

**FRAMEWORK FOR RESIDENTIAL GREENHOUSE GAS MITIGATION IN
KADUNA METROPOLIS**

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KADUNA METROPOLIS**

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**A THESIS SUBMITTED TO THE SCHOOL OF POST GRADUATE STUDIES,
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MAY, 2017

DECLARATION

I declare that the work in this thesis entitled “Framework for Residential Greenhouse Gas Mitigation in Kaduna metropolis” has been carried out by me in the Department of Building. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree or diploma at this or any other institution.

Buhari Mohammed MANZUMA

Signature

Date

CERTIFICATION

This thesis entitled FRAMEWORK FOR RESIDENTIAL GREENHOUSE GAS MITIGATION IN KADUNA METROPOLIS by BUHARI MOHAMMED MANZUMA meets the regulations governing the award of the degree of Doctor of Philosophy in Building Services of the Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

This work is dedicated to Salamatu, Amina, Al-Mustapha, Fatima and Halima.

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ABSTRACT

There are concerns recently about the effects of emissions of greenhouse gases (GHGs) from operation of buildings on the global climate system. Activities related to energy consumption in buildings have been identified as offering the greatest opportunity to mitigation of GHGs. It is against this background that the study set out to develop a framework for mitigation of CO₂ emissions from residential buildings in Kaduna metropolis. The methodology of the study is a field survey. It involved identifying the level of possession of electrical appliances by the 206 households surveyed, the extent of use of the appliances, behaviour of households in relation to energy consumption, determination of the amounts of fuel consumed by households and the calculation of CO₂ emissions attributable to these activities. A structured questionnaire was used for this purpose while a CO₂/Humidity/Temperature Recorder was used to measure the concentrations of the gas released during various domestic fuel-consuming activities. The convenience sampling procedure was adopted. The result shows that a large number of electrical gadgets are owned by the households and that food preparation (35%), lighting (26%) and cooling (18%) respectively consume the greatest quantity of grid electricity and also emit the most CO₂. The direct emissions of CO₂ (5660 kg) from the surveyed households are more than twice the indirect emissions (2063.83 kg). The mean outdoor concentration of CO₂ during the operation of generators (1181ppm) is beyond the ASHRAE limit of between 300 and 400 ppm while the average indoor concentration (625ppm) is within the limit (not greater than 1050 ppm). In the case of cooking fuels, wood produced the greatest CO₂ concentration (1133 ppm) at the source of the emission followed by kerosene (1002 ppm) and LPG (817 ppm). The result also revealed a low level

of observance of energy efficiency measures amongst the households. A framework was developed which is aimed at reduction of CO₂ emissions through good design of new buildings, efficient services design and behavioural adjustments by the building users. The study concludes that the relatively high population size of the households, ownership of a large collection of electrical appliances, inefficient operation of the appliances and consumption of large quantities of biomass and fossil fuels are responsible for the emissions of large quantities of CO₂. The major recommendations from the study are the boosting of the generation and transmission of electricity by government, a shift towards renewable energy sources by the households and embracing of energy efficient measures. The study also recommends further studies into CO₂ emissions from energy use in buildings to develop models that can be used to estimate possible emission reductions as well as determination of emission factors for the various processes in buildings and associated fuel types. The major contributions of the study to knowledge are the determination of average energy consumption and CO₂ emission resulting from this which are respectively 992kWh/capita/year and 1292.52kgCO₂/capita/year. The other major contribution is the framework suggested for CO₂ mitigation in buildings in Kaduna metropolis.

TABLE OF CONTENTS

	Page
Cover Page-----	i
Title Page-----	ii
Declaration-----	iii
Certification-----	iv
Dedication-----	v
Acknowledgement-----	vi
Abstract-----	viii
Table of Contents-----	x
List of Tables-----	xix
List of Figures-----	xxii
List of Plates-----	xxiii
List of Appendices-----	xxiv
Abbreviations-----	xxv

1.0 INTRODUCTION	1
1.1 Background to the Study	1
1.2 Statement of the Research Problem	3
1.3 Justification for the Study	5
1.4 Aim and Objectives	7
1.4.1 Aim	7
1.4.2 Objectives	7
1.5 Research Questions and Hypotheses	8
1.5.1 Research Questions	8
1.5.2 Research Hypotheses	8
1.6 Scope and Limitations	9
1.6.1 Scope	9
1.6.2 Limitations	10
2.0 LITERATURE REVIEW	11
2.1 Greenhouse Gas Emissions	11
2.1.1 Types of Greenhouse Gases	13

2.1.2 Impact of GHGs on Global Warming-----	14
2.1.3 Global Warming Potential of GHGs-----	15
2.2 Buildings and GHG Emissions-----	16
2.2.1 Quantities of GHGs Emitted from Residential Energy Consumption-----	17
2.2.2 Direct and indirect emissions-----	18
2.2.3 Scope of Emissions-----	19
2.3 Sources of Emissions-----	20
2.3.1 Emissions from Electricity Consumption-----	20
2.3.2 Emissions from on-site Energy-----	22
2.3.3 Quantities of Fuels Consumed by Households-----	23
2.4 Quantification of Greenhouse Gas Emissions-----	23
2.4.1 Methods of Measuring Greenhouse Gas Emissions-----	25
2.4.2 Measurement of Carbon Dioxide (CO ₂) Concentrations-----	29
2.5 GHG Emissions Inventory Development Process-----	30
2.5.1 GHG Accounting and Reporting Principles-----	31
2.5.2 GHG Inventory Guidance Materials-----	33

2.5.3 Base Year Selection-----	33
2.5.4 Forecast Years-----	36
2.5.5 Emission Scenarios-----	37
2.5.6 Inventory Data Collection-----	38
2.5.7 Stakeholders in Residential Greenhouse Gas Mitigation-----	41
2.5.8 Residential Energy Consumption-----	42
2.6 Greenhouse Gas Mitigation Strategies-----	43
2.6.1 Setting the Mitigation Target-----	44
2.6.2 Types of Greenhouse Gas Mitigation Options-----	44
2.6.3 Strategies for Residential CO ₂ Mitigation-----	46
2.7 United Nations Framework Convention on Climate Change (UNFCCC) -----	51
2.7.1 Parties to the Convention-----	52
2.7.2 The UNFCCC Guidelines on Mitigation Assessment-----	52
2.7.3 Intergovernmental Panel on Climate Change (IPCC) -----	53

2.8 Greenhouse Gas Mitigation Assessment	53
2.8.1 Steps in Mitigation Assessment	54
2.9 Conceptual Framework	55
2.10 Concepts related to GHG emission reduction	56
2.10.1 Energy Consumption	56
2.10.2 Energy Audit	57
2.10.3 Estimation of Emission	58
2.10.4 Emission Factor (EF)	59
2.10.5 Reduction in Emission	60
2.10.6 Environmental Sustainability	61
2.10.7 Behaviour of Households	62
3.0 RESEARCH METHODOLOGY	64
3.1 The Approach to the Study	64
3.2 The Study Area	64
3.2.1 Geography and Population of the Area	66

3.2.2 Socio-Economic Profile of the Area-----	67
3.2.3 Clusters in Kaduna Metropolis-----	68
3.3 Collection of Data-----	70
3.4 Sources of Data for the Study-----	72
3.4.1 Secondary Sources-----	72
3.4.2 Primary Sources-----	72
3.5 The Data Collection Instrument-----	74
3.6 Sampling-----	75
3.6.1 Sampling Techniques-----	75
3.6.2 Sample Size-----	76
3.7 Measurement of CO₂ Concentrations-----	78
3.7.1 Collection of Samples-----	78
3.7.2 Instrument for CO ₂ Measurement-----	79
3.8 Analysis of Data-----	80

4.0 PRESENTATION AND ANALYSIS OF DATA -----	83
4.1 Characteristics of the Households -----	83
4.2 Energy Consumption Data of the Buildings -----	85
4.2.1 Sources of Energy for Household End Uses-----	85
4.2.2 Energy use for Ventilation-----	87
4.2.3 Energy use for Cooling-----	88
4.2.4 Food Preparation and Cooking-----	89
4.2.5 Energy for Lighting-----	90
4.2.6 Use of Energy for Entertainment-----	91
4.2.7 Energy Use for Laundry-----	92
4.2.8 Use of Energy for Sanitation and Hygiene-----	92
4.2.9 Energy Use by other Household Appliances-----	93
4.3 Onsite Energy Generation and Consumption -----	94
4.3.1 Electricity Generation on Site-----	94
4.3.2 Quantities of Cooking Fuels Consumed by Households-----	95

4.4 Energy Use Patterns and Behavioural Adaptations-----	98
4.4.1 Energy Use Preference-----	98
4.4.2 Behavioural Adaptations-----	100
4.5 Estimation of Baseline Carbon Dioxide Emissions-----	102
4.5.1 Direct CO ₂ Emissions-----	102
4.5.2 Regression Analysis for Determinants of Petrol Consumption-----	104
4.5.3 Indirect CO ₂ Emissions-----	105
4.5.4 Aggregation of Residential Indirect CO ₂ Emissions-----	111
4.5.5 Regression Analysis for Determinants of CO ₂ Emission from Use of A.Cs-----	114
4.5.6 Summary of Energy Consumption and Emission Data-----	115
4.5.7 Comparison of per capita CO ₂ emission with other Countries-----	117
4.6 Emissions for the Forecast Years-----	119
4.6.1 Business as usual scenario (BAU) -----	119
4.6.2 Alternative policy scenario (APS) -----	122
4.6.3 Comparison of the Emission Scenarios-----	125
4.6.4 Analysis of Variance between the Emission Scenarios-----	127

4.7 Measurement of Carbon Dioxide Concentrations-----	128
4.7.1 Concentration of CO ₂ from Operation of Generators-----	128
4.7.2 CO ₂ Concentrations from Cooking-----	130
4.7.3 Concentration of Emissions in the Clusters-----	132
4.8 The Greenhouse Gas Mitigation Framework-----	133
4.8.1 Philosophy behind the Framework-----	133
4.8.2 Development of the Framework-----	134
5.0 SUMMARY OF FINDINGS, CONCLUSION AND RECOMMENDATIONS--	141
5.1 Summary of Findings-----	141
5.2 Conclusion-----	142
5.3 Recommendations-----	143
5.4 Areas for Further Studies-----	144
REFERENCES-----	145
APPENDICES-----	156

LIST OF TABLES

	Page
Table 2.1: GWP values of the Commonest GHGs-----	16
Table 2.2: Summary of Electricity Generation in Nigeria-----	20
Table 2.3: The Categories of Mitigation Options-----	45
Table 3.1: Local Governments and Population of Kaduna Metropolis-----	66
Table 3.2: Population of Houses in Kaduna Metropolis-----	77
Table 4.1: Characteristics of the Houses-----	84
Table 4.2: Data on Energy Consumption in Buildings-----	86
Table 4.3: Ventilation Energy Consumption Data-----	87
Table 4.4: Cooling Energy Consumption Data-----	88
Table 4.5a: Data on Lighting in Studied Households-----	90
Table 4.5b: Other Lighting Data-----	90
Table 4.6: Possession of Entertainment Equipment and Daily Energy Use Data-----	91
Table 4.7: Weekly laundry energy use data-----	92
Table 4.8: Households' Weekly Energy use Data for Sanitation and Hygiene-----	93
Table 4.9: Weekly Energy Use Data from other Household Appliances-----	93
Table 4.10: On-site Energy Generation and Consumption-----	94
Table 4.11: Types of fossil fuels and biomass used for cooking by surveyed houses-----	95
Table 4.12: Quantity of kerosene consumed by households monthly-----	96
Table 4.13: Quantity of LPG consumed by households-----	96

Table 4.14: Summary of quantities of biomass and fossil fuels consumed-----	97
Table 4.15: Households Preference of Energy Type for Cooking-----	98
Table 4.16: Level of Observance of Energy Efficiency Measures-----	99
Table 4.17: Willingness of Households to Accept Behavioural Changes-----	101
Table 4.18: Direct Baseline Emissions of CO ₂ Annually-----	103
Table 4.19: Regression Analysis for Factors Affecting Petrol Consumption-----	104
Table 4.20a: Baseline CO ₂ Emissions from cooling, lighting and ventilation-----	106
Table 4.20b: Baseline CO ₂ Emissions from electrical kitchen appliances-----	108
Table 4.20c: Baseline CO ₂ emissions from entertainment-----	109
Table 4.20d: Baseline CO ₂ emissions from household sanitation and body hygiene-----	110
Table 4.20e: Baseline emissions from the use of other household appliances-----	111
Table 4.21: Multiple Regression Analysis for Energy Consumption by A.Cs-----	114
Table 4.22: Summary of energy use and emission data for the surveyed houses-----	116
Table 4.23: Comparison of Per Capita CO ₂ Emissions from Building Use-----	118
Table 4.24: Projected Direct Emissions for the Business as usual Scenario (Case A) ----	120
Table 4.25: Projected Direct Emissions for the Business as usual Scenario (Case B) ----	120
Table 4.26: Projected Indirect Emissions for the Business as usual Scenario (Case A) -	121
Table 4.27: Projected Indirect Emissions for the Business as usual Scenario (Case B) -	122
Table 4.28: Alternative Policy Scenario DEs from the Surveyed Houses (A) -----	123
Table 4.29: Alternative Policy Scenario DEs from the Surveyed Houses (B) -----	123
Table 4.30: Projected Indirect Emissions for the Alternative Policy Scenario (A) -----	124
Table 4.31: Projected Indirect Emissions for the Alternative Policy Scenario (B) -----	124
Table 4.32: Results of the one-way ANOVA between Emission Scenarios-----	127

Table 4.33: CO₂ Concentrations (PPM) Measured during Operation of Generators-----128

Table 4.34: Concentrations (PPM) of CO₂ from Cooking with Different Fuels-----130

Table 4.35: Average Outdoor CO₂ Concentration in the Different Clusters-----132

Table 4.36: Correlation of Population Density of Clusters and CO₂ Concentrations-----133

LIST OF FIGURES

	Page
Figure 2.1: Conceptual Framework for the Study-----	63
Figure 3.1: Local Government Areas in Kaduna State-----	65
Figure 3.2: The local governments and the neighbourhoods in Kaduna metropolis-----	70
Figure 4.1: Households' Possession of Food Preparation and Cooking Appliances-----	89
Figure 4.2: Electrical Energy Use by the Household Activities-----	112
Figure 4.3: Fraction of Electricity from Thermal Plants-----	113
Figure 4.4: Indirect CO ₂ Emissions from households by energy use category-----	113
Figure 4.5: Business as usual and Alternative Policy Scenario CO ₂ Emissions-----	125
Figure 4.6: Framework for Mitigation of CO ₂ from Residential Buildings in Kaduna----	135

LIST OF PLATES

	Page
Plate I: The CO ₂ / Humidity/ Temperature Data Recorder and the CO ₂ Sensor-----	169
Plate II: Measurement of outdoor concentration of CO ₂ from a generator-----	169
Plate III: Measurement of CO ₂ concentration during cooking with LPG-----	170
Plate IV: Measurement of CO ₂ concentration during cooking with kerosene-----	170

LIST OF APPENDICES

	Page
Appendix 1: The Questionnaire-----	156
Appendix 2: Power Ratings of Common Household Appliances-----	165
Appendix 3: Questionnaire Responses-----	166
Appendix 4: Electricity Emission Factors-----	168
Appendix 5: Illustrations of the Empirical Study-----	169

ABBREVIATIONS

CFC	-Chlorofluorocarbon
EPA	-Environmental Protection Agency
GDP	-Gross Domestic Product
GHG	-Greenhouse gas
GWP	-Global Warming Potential
HCFC	-Hydro chlorofluorocarbon
ICLEI	-International Council for Local Environmental Initiatives
IEA	-International Energy Agency
IPCC	-Intergovernmental Panel on Climate Change
NGO	-Non-governmental Organizations
SBCI	-Sustainable Building and Climate Initiative
UNEP	-United Nations Environment Programme
UNFCCC	-United Nations Framework Convention on Climate Change
WBCSD	-World Business Council for Sustainable Development
WRI	-World Resources Institute

CHAPTER ONE

1.0

INTRODUCTION

1.1

Background to the Study

Global warming is a phenomenon that has been of great concern to world leaders, climate scientists, biologists and conservationists for a long time because of its devastating effect on the global climate system. The emission of greenhouses gases (GHGs) from human activities has been identified as the main cause of this warming of the earth. Emission of GHGs from the operation of buildings and their effects on the climate is one of the issues that have dominated discussions on global climate change for some time now (Sun *et al*, 2014). The most recent of these discussions include the climate change conferences held at Warsaw in 2013, Doha in 2012, Durban in 2011, Cancun in 2010 and Copenhagen in 2009 (Shah, 2013). Ramaswami *et al* (2010) observed that the main source of GHG emissions from buildings is energy consumption and they also identified energy use reduction in buildings especially residential buildings as one of the strategies for large scale GHG mitigation. Even though it is established that majority of the emissions in the past and currently originated from the industrialized nations of the world such as America, Canada, Russia and so on, it is projected that in the very near future the level of emissions from buildings in rapidly industrializing countries like China will surpass emission levels from buildings in developed countries (UNEP, 2009a).

Now that the population of cities worldwide is more than half of the global population, the inhabitants of cities must be made aware of the key role they have to play in the mitigation

of GHG emissions (Satterthwaite, 2008 in Kennedy *et al*, 2010). In an attempt to brace up to this challenge of addressing climate change many cities such as Frankfurt, Paris, New York, Toronto, Chicago, Sydney, Colombo, London, Manchester, Cape Town and so on have established inventories of GHG emissions. The International Council for Local Environmental Initiatives, ICLEI, (2008) in Kennedy *et al*, (2010) posited that such inventories of urban GHG emissions serves as a benchmark for assessing action on climate change.

Levine *et al* (2007) asserted that in 2004, emissions due to on site combustion of different types of fuel to meet the energy needs of the building sector amount to 3 GtCO₂, 0.4 GtCO₂-eq CH₄, 0.1 GtCO₂-eq N₂O and 1.5 GtCO₂-eq halocarbons (including chlorofluorocarbons and hydro-chlorofluorocarbons). Levine *et al* pointed out that since GHG mitigation in the building sector involves a lot of measures aimed at energy efficiency, it is useful to compare the mitigation potential with carbon dioxide emissions, including those through the use of electricity.

Moreover the International Energy Agency (IEA) has observed that the emission of GHGs from buildings is closely related with energy use and that the rural communities of many developing countries rely mostly on burning fuel wood and other forms of biomass such as sawdust, crop residues and animal dung to meet their energy needs. The IEA estimates that as many as 2.4 billion people worldwide use biomass for their domestic energy needs, and that there is a higher probability of this figure increasing in the future (IEA, 2002 in UNEP, 2009a). Many households in many countries use inefficient technologies to burn the fuel and this result in emission of large quantities of GHGs. Nevertheless it has been observed

that the emission of GHGs in Nigeria is on the average low because of the low per capita energy and other resources consumption in the country but these are expected to rise in the future as a result of the high population growth rate, and corresponding increase in per capita energy and other resource consumption (Ministry of Environment of the Federal Republic of Nigeria 2003; Chah and Igbokwe, 2012).

According to Environmental Protection Agency, EPA, (2013a) a greenhouse gas inventory is an accounting of GHGs emitted to or removed from the atmosphere over a period of time. Policy makers use inventories to establish a baseline or a reference for tracking emission trends, developing mitigation strategies and policies, and evaluating the effectiveness of the mitigation strategies. The development of an emissions inventory is usually the first step taken by entities that want to reduce their emission of GHGs. EPA (2013a) also stated that a complete and transparent national GHG inventory is an essential tool for understanding emissions and trends, projecting future emissions and identifying sectors for cost-effective emission reduction opportunities. However ICLEI (2007) has pointed out that all inventories are necessarily estimates based on the best available data and procedures and as such are subject to change with time especially when faults are detected in the data used for preparing them.

1.2 Statement of the Research Problem

The Intergovernmental Panel on Climate Change (IPCC) has proposed a reduction in global CO₂ emissions by half by the year 2050 from the estimated present level of 380 parts per million (ppm). This advice originated from the need to avoid the worst impacts from

climate change due to human interference. Hassol (2011) affirmed that absolution from the most severe consequences of climate change will require the total global average warming to be kept within 2°C relative to pre-industrial era levels. Tufts Climate Initiative (2002) and Gupta and Garrigan (2013) established that for communities to be capable of reducing their GHG emissions and also be able to assess the effectiveness of their GHG mitigation measures, they first need to know which activities are the highest emitters and how much they are emitting. When this is done opportunities for emission reduction can be identified and even the extent of possible emission reduction can be estimated. ICLEI (2007) is of the view that since each local community has unique characteristics (such as population, housing types, transportation networks, industries, electricity fuel mix) that can substantially differentiate its GHG inventory from those of other cities or counties, it is recommended that energy audit for emission assessment be conducted for each community to identify these peculiarities.

Levine *et al* (2007) reported a great literature and data dearth about GHG emissions and mitigation options in developing countries and Nigeria is no exception. They observed that although the situation is somewhat better in the industrialized nations, the same cannot be said of a larger percentage of countries because the relevant data is poorly collected and reported. Furthermore literatures on GHG mitigation in agricultural (Achike *et al*, 2012; Chah and Igbokwe, 2012) and manufacturing (Ibikunle, 2006; Federal Ministry of Environment and United Nations Development Programme, 2009) sub-sectors abound but studies that are specifically targeted at residential GHG mitigation in Nigeria are scanty. This study is intended to bridge some of that gap.

GHG mitigation frameworks exist for most cities and regions of the industrialized nations but these are not suitable for use in the Nigerian context because of the wide differences in energy usage and behavioural patterns. Even adoption and adaption cannot be done without a detailed energy study of the community and development of an inventory of GHG emissions.

1.3 Justification for the Study

The building sector worldwide consumes up to 40% of all energy and is also accountable for about 30% of global annual GHG emissions (UNEP SBCI, 2009). It has been observed that with the high increase in the rate of new construction in transiting economies, and coupled with the inefficiencies of existing building stock worldwide, if no deliberate action is taken, GHG emissions from buildings have the potential to more than double in the next two decades. In the vast majority of countries the residential sector is responsible for the greatest consumption of total primary energy. Takaoka (2011) observed that there is the possibility of reducing energy consumption in both new and existing buildings by an estimated 30-50% by 2020.

UNEP (2009a) avowed that those in authority must be proactive in dealing with the issue of emission reduction from the building sector if targets for GHG emissions reduction to close to pre-industrial era levels of about 300ppm are to be met. Mitigation of GHG emissions from buildings must be pursued with urgency because the building sector offers the greatest prospect for delivering an enduring, significant and cost-effective reduction in GHG emissions (UNEP, 2009a).

UNEP (2009b) observed that reducing emissions from buildings will bring multiple benefits to both the economy and to the society in general. The construction, renovation, and maintenance of buildings contribute 10 to 40 percent of countries' Gross Domestic Product (GDP), and represent on a global average 10 percent of country-level employment. UNEP (2009a) also posited that if GHG mitigation strategies for buildings are carefully planned, they can stimulate the growth of new businesses, jobs, and contribute to social development goals such as better housing and access to clean energy and water.

It is important that local inventories establish a clear emissions baseline that can be used to monitor future progress since they are not prepared as frequently as other types of inventories (EPA, 2013b). Also, because of the direct correlation between GHG emissions and energy consumption, attempts at cutting down on the level of emissions will also be promoting energy efficiency. This is of great importance especially in countries like Nigeria where the supply of electricity to the various sectors is insufficient. Furthermore the assessment of options to reduce future GHG emissions has been considered as an important contribution to the sustainable development of Nigeria by the Ministry of Environment of the Federal Republic of Nigeria (2003).

A justification of the choice of Kaduna for this study can be found in the assertion by Sun *et al* (2014) that cities which occupy less than 1% of the earth surface accommodates over 50% of the global population and emit about 80% of GHGs globally. Kaduna is a typical city in Nigeria. Also, since the effects of the emissions on the climate are not localized to the area from which they originate, it becomes very vital for all communities and entities to be able to determine how much they are emitting so that appropriate mitigation measures

can be put in place. This is why it is important for even low emitters like Nigeria to put in place a framework for mitigation of GHGs. These highlighted concerns necessitate the development of an inventory for each community and justify a study of this nature.

1.4 Aim and Objectives

1.4.1 Aim

The study aims to develop a framework for residential carbon dioxide mitigation in Kaduna metropolis with a view to defining a road map towards the reduction of emission of carbon dioxide from domestic energy consumption activities.

1.4.2 Objectives

The objectives of the study are to:

- i. Synthesize information about residential buildings in Kaduna metropolis.
- ii. Generate data on energy consumption by the residential buildings.
- iii. Estimate the direct and indirect emissions of CO₂ for a base year and some forecast years.
- iv. Investigate the behaviours of households as it relates to CO₂ emissions.
- v. Measure the indoor and outdoor concentrations of CO₂ in and around selected households.
- vi. Develop a framework for mitigation of CO₂ emissions from residential buildings in Kaduna metropolis.

1.5 Research Questions and Hypotheses

1.5.1 Research Questions

The following questions were asked by the study hoping that the answers provided will contribute in directing towards mitigation of GHGs:

- i. What are the main sources of energy for domestic use in Kaduna metropolis?
- ii. What is the extent of residential energy consumption in Kaduna metropolis?
- iii. What are the baseline and forecast emissions of carbon dioxide (CO₂)?
- iv. Are there any substantial differences between the different scenarios of emissions?
- v. Are there discernible differences in the average global atmospheric concentration of CO₂ and that of the surveyed area?
- vi. How can CO₂ emissions from residential buildings be effectively reduced?

1.5.2 Research Hypotheses

The following hypotheses were developed to guide further investigations into the anthropogenic GHG emission problem:

- I. There is no difference in CO₂ emissions from the different scenarios. This is called the Null hypotheses, H₀.

$$H_0: \mu_1 = \mu_2 = \mu_3 \dots = \mu_k$$

- II. The CO₂ emissions from the different scenarios are different. This is the alternative hypothesis, H_A.

H_A: The means of emissions from the different scenarios are not the same.

1.6

Scope and Limitations

1.6.1 Scope

Many anthropogenic activities emit greenhouse gases. Examples of these activities are manufacturing, transportation (road, air, etc.), agriculture, energy generation and transmission and operation of buildings as well as waste generation and deforestation. The extent of emission from the different activities also differs. This work is limited in scope to energy related emissions in residential buildings in Kaduna metropolis only. While all stages of a building's life-cycle including construction and demolition produce carbon emissions, the building's operational phase accounts for 80-90% of emissions resulting from energy use mainly for heating, cooling, ventilation, lighting and appliances and it is this stage of the building's life-cycle that is the focus of this study. The study also focused on the emission of carbon dioxide (CO₂) only since it is accountable for over 98% of all energy related emissions from the operation of buildings. Emission of GHGs from residential solid waste generation has not been included in this study.

GHG emission reduction targets are intended at reducing emissions to close to pre-industrial era levels of around 300ppm. To facilitate the achievement of this, the study also involves measurement of CO₂ concentrations in and outside the buildings to know the present levels.

1.6.2 Limitations

Government agencies in Nigeria are not reputed for keeping up to date information about their activities and other public concerns and non-governmental organizations (NGOs) that could bridge this gap also do not exist. Households or citizens do not also fare any better in this regard. In view of this access to good data about energy consumption and efficiency is one factor that posed serious challenge to the success of the research. The willingness of the stakeholders to give objective responses to the questions in the questionnaires administered to acquire information on buildings and energy use also posed some challenges to the study. Moreover the level of awareness of the buildings occupants and users about the energy performance requirements and indicators of the buildings they live in is also a limiting factor for this work.

Another limitation to the study concerns the generation of primary data on two of the mitigation measures proposed in the framework. Since completed and inhabited buildings were surveyed, the study could only collect data on the behaviours of the users and likely modifications to these behaviours. There is no way the study could have obtained the data on measures that could be taken at the building and services design stage than through theoretical means (literature). While the energy efficiency of the existing buildings can be improved through the behavioural changes and some alterations to the buildings and their systems, the mitigation measures on building and services design can be applied to new developments in the communities.

CHAPTER TWO

2.0 REVIEW OF LITERATURE

2.1 Greenhouse Gas Emissions

Greenhouse gases are gases that trap heat in the atmosphere leading to a gradual increase in the global atmospheric temperature. Emrath and Liu (2007) defined GHGs as chemicals that, when released into the atmosphere, have the potential to cause global warming. Walser (2013) declared that the existence of greenhouse gases in the atmosphere has maintained the average temperature of the Earth at 14°C (57°F). In the absence of the greenhouse effect, the average global atmospheric temperature would have been -19°C (-2.2°F) which would make life on earth an impossibility. Global warming has received a lot of attention lately. Part of this attention has fallen upon the housing sector and the role it plays in generating greenhouse gases through the consumption of grid electricity and fossil fuels.

Some GHGs such as carbon dioxide (CO₂) occur naturally and are emitted to the atmosphere through natural processes as well as through some anthropogenic activities. Other GHGs particularly the fluorinated gases are created and emitted solely through anthropogenic activities. The principal GHGs that enter the atmosphere because of human activities are: Carbon dioxide, methane, nitrous oxide and fluorinated gases (B Corporation, 2008). The Intergovernmental Panel on Climate Change (IPCC) estimated that 97 percent of CO₂ emissions worldwide in the 1990s came from natural sources (Emrath and Liu, 2007) but also observed that the additional 3% that resulted from human activity was enough to push emissions above the capacity of natural processes (such as photosynthesis)

to absorb them. Emrath and Liu (2007) posited that it is in this way that anthropogenic emissions are responsible for the rising concentrations of CO₂ measured in the atmosphere.

It is documented in EPA (2014a) that in 2010, estimated worldwide emissions from human activities totaled nearly 46 billion metric tons of greenhouse gases, expressed as CO₂ equivalents. This represents a 35 percent increase from 1990. The United Nations Framework Convention on Climate Change, UNFCCC, (2009) has revealed that the largest growth in GHG emissions has come from energy supply and road transport. This is in agreement with Emrath and Liu's (2007) proclamation that the largest components of greenhouse gases generated by human activity over the course of a year result from energy that is produced and consumed. A sizeable chunk of this energy is used in buildings for various activities and processes which also release GHGs. Different studies have given various figures (percentages) for residential energy use in different countries and the values range from 16% in Mexico (UNEP, 2009b) and South Africa (UNEP, 2009c) to 22.6% in America (Intermediate Energy Infobook, 2012) and 18% as the World average in 2008 (EIA, 2013).

Greenhouse gases comprise less than 1% of the atmosphere. Their levels are determined by a balance between sources and sinks. Sources are processes that generate and sinks are processes that destroy GHGs respectively (EPA, 2016). Humans disturb the levels of GHGs in the atmosphere by introducing new sources or by destroying natural sinks. Human induced changes in the constituents of the atmosphere are perhaps the greatest threat that the global climate system has to contend with (Stubbs, 2009 and NOAA National Marine Fisheries Service and United States Fish and Wildlife Service, 2009). In recognition of this threat and the need to urgently address it, the United Nations Framework Convention on

Climate Change (UNFCCC) was accented to by 161 countries at the earth summit in Rio de Janeiro in 1992. The objective of this international treaty is to achieve stabilization of GHG concentrations in the atmosphere at a level that would not cause dangerous anthropogenic interference with the global climate system (UNFCCC, 2009).

2.1.1 Types of Greenhouse Gases

The six GHGs covered by the UNFCCC and its Kyoto Protocol are as follows:

- i. Carbon dioxide (CO₂) resulting mainly from energy generation and consumption through burning fossil fuels (such as oil, natural gas and coal), solid waste and deforestation (EPA, 2014 and Forster *et al*, 2007).
- ii. Methane (CH₄) produced from agricultural activities, energy production, natural gas distribution and anaerobic decay of organic waste in landfills. It account for 14.3% of global emissions in 2004 (EPA, 2014 and Forster *et al*, 2007).
- iii. Nitrous oxide (N₂O) whose main source is agriculture (accounting for 70% of its emission in 2010). Other less emitting sources are fuel combustion and manufacturing (International Energy Agency, 2012).
- iv. Hydrofluorocarbons (HFCs) used as replacement for ozone-depleting substances.
- v. Perfluorocarbons (PFCs) also used as replacement for ozone-depleting substances.
- vi. Sulphur hexafluoride (SF₆) used in some industrial processes and in electric equipment (UNFCCC, 2009).

The last three GHGs are jointly referred to as fluorinated gases. They do not occur naturally and together contributed 1.1% of global GHG emissions in 2004 (UNFCCC, 2009). Most of the emissions of fluorinated gases are from annex 1 countries (International Energy Agency, 2012). The GHG inventory is used to track the three most abundant GHGs namely Carbon dioxide (CO₂), Nitrous oxide (N₂O) and Methane (CH₄), expressed as a CO₂ equivalent (CO₂e) (Federation of Canadian Municipalities, FCM, 2008).

2.1.2 Impact of GHGs on Global Warming

Climate scientists have observed that carbon dioxide (CO₂) concentrations in the atmosphere have been increasing significantly over the past century, compared to the rather steady level of about 280 parts per million in volume, ppmv, of the pre-industrial era (International Energy Agency, 2013). The 2012 concentration of CO₂ (394 ppmv) was about 40% higher than in the mid-1800s, with an average growth of 2 ppmv/year in the last decade. The highest atmospheric concentration of CO₂ measured for the first time in probably millions of years was 400 ppm in 2013 (Nova Analytical Systems, 2015). The International Energy Agency, IEA, (2013) has observed significant increases in the levels of methane and nitrous oxide in the atmosphere over the years. EPA (2014a) posited that greenhouse gases from human activities are the most significant driver of observed climate change since the mid-20th century and this is one reason why communities must pay adequate attention to the mitigation of GHG emissions especially CO₂ because it is the most abundant in the atmosphere.

It has been observed that as GHG emissions from human activities increase, they accumulate in the atmosphere and warm the climate, leading to many other changes around the world—in the atmosphere, on land, and in the oceans. These changes have both positive and negative effects on people, society, and the environment—including plants and animals and because many of the major GHGs stay in the atmosphere for many years after being released, their warming effects on the climate persist over a long time and can therefore affect both the present and generations unborn. The gases become globally mixed in the lower atmosphere, reflecting contributions from emissions sources worldwide (Environmental Health and Safety Online, 2016).

2.1.3 Global Warming Potential of GHGs

Different GHGs exert different effects on the Earth's energy balance and in order to assist policy makers to measure the impacts of various GHGs on global warming, the IPCC introduced the concept of Global Warming Potentials (GWPs) in 1990. GWP reflects the relative strength of individual GHGs with respect to its impact on global warming. It was defined as the cumulative radiative forcing between the present and some future time caused by a unit mass of GHG emitted now, expressed relative to CO₂ (Trottier, 2015; EPA, 2002). In other words, radiative forcing is the ability of a GHG to trap heat in the atmosphere.

According to Emrath and Liu (2007), while CO₂ has a greater impact on global warming than other GHGs the non-CO₂ GHGs have much greater “global warming potentials” per metric ton. For example in the recent IPCC assessment, a metric ton of methane has twenty

three times the global warming potential of a metric ton of CO₂. For many GHGs the ratio is over 1,000 to 1. In line with the earlier assertion by Emrath and Liu (2007), Collopy (2008) pointed out that while CO₂ is not as potent a GHG as the other GHGs, its effect dwarfs all the other GHGs combined because it is produced in enormous quantities. Therefore, greenhouse emissions are reported as though they were equivalent to a given volume of CO₂. Using CO₂e as a measure of greenhouse emissions allows for a comparison of the greenhouse impact of a variety of greenhouse emissions sources. Table 2.1 presents the commonest GHGs with their global warming potential (GWP) values.

Table 2.1: GWP values of the Commonest GHGs

Formula	Common Name	GWP
CO ₂	Carbon dioxide	1
CH ₄	Methane	25
N ₂ O	Nitrous oxide	298
SF ₆	Sulphur hexafluoride	22800

Source: IPCC Fourth Assessment Report (2007) in Greenhouse Gas Protocol

2.2 Buildings and GHG Emissions

Greenhouse gas emissions from buildings arise mainly from their consumption of fossil-fuel based energy, both through the direct burning of fossil fuels and through the use of electricity which has been generated from fossil fuels. Significant greenhouse gas emissions are also generated through construction materials, particularly insulation materials, and refrigeration and cooling systems (UNEP, 2009b). It has also been observed in UNEP (2009c) that the level of GHG emissions from buildings is closely correlated with the level

of demand, supply and source of energy. Lin *et al* (2013) opined that household lifestyle is a major driver of energy use and related GHG emissions besides technology efficiency. In view of this, data on household lifestyle is emphasized in the collection of primary data.

Literature has it that as countries develop, traditional fuels are complemented and replaced by electricity and gas. The implication is that the potential for GHG emissions increases profoundly for two main reasons. Access to electricity can stimulate demand for electrical appliances, thereby increasing demand for energy over and beyond the level it had been before electricity was available (UNEP, 2009a). More significantly, the generation of electricity itself is a major source of GHG emissions, unless it comes from renewable sources such as hydroelectric power plants and solar energy, or from nuclear energy (UNEP, 2009a). Unfortunately, electricity generation in Nigeria at present is mainly from non-renewable sources.

2.2.1 Quantities of GHGs Emitted from Residential Energy Consumption

Emrath and Liu (2007) avowed that almost all residential greenhouse emissions are CO₂, and CO₂ emissions are strongly related to energy consumption. They stated that the residential sector accounts for 21-22% of both energy consumption and CO₂ emissions. The residential sector however does not generate much of other GHGs and so accounts for only 18% of total GHG emissions measured in Million Metric Tonnes of CO₂ equivalents.

As reported by Emrath and Liu (2007), CO₂ accounts for over 98% of GHG emissions in residential buildings. They reported that all residential CO₂ emissions are energy-related. It was noted that about 99 percent of residential methane emissions come from the relatively

inefficient combustion of wood in fireplaces and woodstoves. 100 percent of residential nitrous oxide emissions result from some type of combustion—75 percent from combustion used to generate electricity. 100 percent of residential sulfur hexafluoride emissions are due to the substance escaping from electric utility transmission and distribution systems, where it is used as an electrical insulator. Thus, almost all residential greenhouse gas emissions are related to energy consumption in one way or another (Emrath and Liu, 2007).

The foregoing proclamations are further buttressed by Simmons (2000) in his assertion that anthropogenic emissions of carbon dioxide (CO₂) weighted by global warming potentials, constitute by far, the largest part of the emissions of GHGs. Of these CO₂ emissions, those that are produced from fuel combustion make up the great majority and, almost all, may be directly and immediately estimated from the combustion activities.

2.2.2 Direct and Indirect Emissions

GHG emissions are broadly classified into two: direct and indirect. Direct emissions are those produced as a result of consumption of energy by an end user within the boundaries of the community whereas indirect emissions are those attributable to the consumption of grid generated electricity. A householder who switches on a gas cooker or a kerosene stove is creating a direct emission. The gas or kerosene is burned, and air pollutants are emitted directly into the air. A householder who uses electricity — for example, by switching on a fan is typically creating an indirect emission, because the actual emissions are produced upstream at a power plant, which may be burning fossil fuel to produce the electricity.

Although the power plant is responsible for emissions associated with the burning of fossil fuels to produce electricity, the emissions are accounted for by the users of the generated electricity (FCM-ICLEI, 2008).

2.2.3 Scope of Emissions

The World Business Council for Sustainable Development/World Resources Institute, WBCSD/WRI, (2001) classified the GHG emissions attributed to cities and local regions as follows:

Scope 1 – Direct GHG emissions that occur within the territorial boundary of the city or local region.

Scope 2 - Indirect emissions that occur outside of the city boundary as a result of activities that occur within the city, limited to only electricity consumption and district heating.

Scope 3 - Other indirect emissions and embodied emissions that occur outside of the city boundary, as a result of activities of the city, including (but not limited to) electricity transmission and distribution losses and solid waste disposal.

The most predominant source of CO₂ emissions is the burning of fossil fuels through the generation of electricity, natural gas and motor fuel use. A small amount of CH₄ and N₂O is also released from these activities. Additionally, CH₄ and N₂O are also produced through agricultural processes and wastewater treatment and CH₄ is released from landfills (Collopy, 2008).

2.3

Sources of Emissions

Emissions of GHGs associated with buildings can be grouped into three classes namely emissions associated with consumption of electricity generated away from the building's location, emissions from on-site energy or fossil fuel combustion and emissions associated with the generation and disposal of wastes (Center for Climate and Energy Solutions, 2016).

2.3.1. Emissions from Electricity Consumption

Electricity generation in Nigeria is mainly from gas and hydropower plants. Table 2.2 shows the summary of the installed and available capacities of the generating stations in Nigeria as at 2011. A small amount of diesel and fuel oil is still used in some generating stations, while gasoline and diesel are used for private generation (Ministry of Environment of the Federal Republic of Nigeria, 2003).

Table 2.2: Summary of Electricity Generation in Nigeria

S/no	Classification	Type	Capacity (MW)	
			Installed	Available
1	Government owned power stations	Hydro	1900	1380
2	Government owned power stations	Thermal	5004.6	1978
3	Independent power projects	Thermal	1759	1484
4	National integrated power projects	Thermal	4775	0

Source: Bureau of Public Enterprises (BPE), 2011.

Table 2.2 shows the combined available power generation from the three hydro plants at Kainji, Jebba and Shiroro to be 1380MW while the total available power from the thermal plants is 3462MW. These combine to give a total of 4842MW. The figure given by Awosope (2014) is not too far from this. BPE (2011) gave the average power generation in Nigeria to be 3200MW. Computations from the figures in Table 2.2 gave 28.5% of electricity available from the National Grid in Nigeria to be from hydroelectric dams while the remaining 71.5% is from thermal plants.

According to Wilson (2012) about 80% of people in the world have access to electricity. This figure has increased in the last decade, mainly due to increasing urbanization. But despite the fact that more and more people are getting access to electricity, different amounts of it is available to users in different parts of the world. According to Wilson (2012) the average American or Canadian household in 2010 used about twenty times more than the typical Nigerian household, and two to three times more than a typical European home. In the US typical household power consumption is about 11,700 kWh each year, in France it is 6,400 kWh, in the UK it is 4,600 kWh, in China around 1,300 kWh and in Nigeria it is 570 kWh. The global average electricity consumption for households with electricity was roughly 3,500 kWh in 2010 (Wilson, 2012; World Energy Council, 2010).

According to The World Bank (2014) the carbon footprint for Nigeria in 2010 was 0.5 metric tons per capita. The carbon footprint is the measure of the amount of GHGs, measured in units of CO₂, produced by human activities. The average American generates 17.6 tons of CO₂-eq each year. The global average carbon footprint is about 4 tons of CO₂-eq per year (The World Bank, 2014).

2.3.2 Emissions from on-site Energy

Activities like cooking and lighting are done in many households in Nigeria by burning fossil fuels such as gas (liquefied natural gas, LNG, and liquefied petroleum gas, LPG), kerosene, coal, and biomass such as wood and dung. This is because many of the households are either not connected to grid electricity or the lack of the electricity for use even in the grid-connected houses for the most part of the times. To augment this shortage, many households rely on portable generators for their power needs (Olaleye and Akinbode, 2011; Stanley *et al*, 2012; Mbamali *et al* 2012). The generators either use petrol or diesel to operate them both of which emit a lot of GHG gases during their combustion.

The International Energy Agency (2013) observed that among the many human activities that produce GHGs, the use of energy represents by far the largest source of emissions. This assertion is also upheld by Simmons (2000) who went further to say that good quality estimates of CO₂ emissions from fuel combustion are not only essential for the construction of inventories and the monitoring of emission control obligations but, because of the potential control measures implicit in the direct link between fuel use and emissions, the estimates are invaluable for the preparation and analysis of emission abatement policies. Simple methods for estimation of CO₂ emissions from the use of fuels assume that the carbon in the fuel used for each activity will enter the atmosphere in the short or long term (Simmons, 2000). Based on the foregoing, the research adopted the option of using household level fuel consumption to estimate CO₂ emissions for the construction of inventory and monitoring of emission control strategies.

2.3.3 Quantities of Fuels Consumed by Households

The main types of fuels used by Nigerian households to meet their energy needs are kerosene, firewood, sawdust, petrol, diesel and liquefied petroleum gas (LPG). Ibrahim and Ukwenya (2010) estimated that between 9 – 20 kilograms of wood is used by households in Benue state on a daily basis while daily kerosene consumption by households that uses it ranges between 0.02 – 0.1 litres.

However, Ojo and Chuffor (2013) estimated that an average of 6.8kg of wood is burnt by each household that uses it as its source of fuel on a daily basis while the average daily per capita consumption is 1.1kg. This puts the per capita annual consumption at 401.5kg. Zaku *et al* (2013) estimated that 0.776kg of wood is consumed per capita daily in Kaduna state. The annual per capita liquefied petroleum gas (LPG) consumption in Nigeria ranges between 0.2kg and 1.0kg (Quaye-Foli, 2002 and Ahmed, 2013). Therefore, it is one of the core objectives of this study to identify sources of energy, level of energy consumption and emission of CO₂ among the households in Kaduna metropolis.

2.4 Quantification of Greenhouse Gas Emissions

The carbon footprint of an individual, organization or nation can be measured by undertaking a GHG emissions assessment or other calculative activities denoted as carbon accounting. Once the size of a carbon emission is known, a strategy can be devised to reduce it, e.g. by technological developments, better process and product management, changed Green Public or Private Procurement (GPP), carbon capture, consumption strategies, carbon offsetting and others.

According to Federation of Canadian Municipalities, FCM, (2008) a GHG emissions inventory is a collection of data that quantifies the amount of energy consumed and solid waste generated by a community and municipal operations. The GHG emissions inventory can be used to estimate a community's emissions in future. The forecast projects future emissions based on assumptions about population, economic growth and types of fuels consumed (FCM, 2008). Lindquist *et al* (2007) observed that most inventories developed at the state, national, and local levels are developed primarily on a direct emission basis probably because such inventories permit cumulative addition of emissions without double counting.

Oorbeck and Ly (2009) posited that GHG emissions can be quantified in two ways. These are measurement-based methodologies and calculation-based methodologies. Measurement-based methodologies refer to the direct measurement of GHG emissions (using a monitoring system) from the flue of a power plant, wastewater treatment plant, landfill, or industrial facility. Direct measurement of GHG emissions by monitoring their concentration and flow rates from a stack is not common and is generally limited to stationary combustion sources (Oorbeck and Ly, 2009). GHG emissions are more often derived from a calculation-based approach, using either a mass balance basis specific to a source or process or, more commonly, documented emission factors.

Calculation-based methodologies calculate emissions using activity data and emission factors. To calculate emissions accordingly, the extent to which an activity occurs is estimated and this is multiplied by the emission factor for that activity. Activity data refer to the relevant measurement of energy use or other greenhouse gas-generating processes

such as fuel consumption by fuel type, electricity consumption, and annual vehicle miles traveled. The calculation-based approach is the most appropriate for this research because the activity data can be generated from the surveyed households by analysing their responses to questions related to energy use and estimating their consumption from this.

2.4.1 Methods of Measuring Greenhouse Gas Emissions

Simple methods for estimation of CO₂ emissions from the use of fuels assume that the carbon in the fuel used for each activity will enter the atmosphere in the short or long term. Short-term emissions are defined within the IPCC Guidelines as those occurring within twenty years of the fuel use and are almost entirely reported in the fuel combustion module. Long-term CO₂ emissions result from the final oxidation of long-life materials manufactured from fuel carbon and are usually emissions from waste destruction (Simmons, 2000).

Top down approach estimate the eventual carbon emissions from the supply of fuels to the economy or the main economic sectors rather than from the fuel consumption or actual emissions at combustion plants. More detailed bottom up methods do not depart from the principle of estimating emissions from the carbon content of the fuel but, as far as possible, use figures for the amounts of fuel consumed at individual large combustion plants together with details of fuel supplies to other sources of emissions. In other words, the bottom up approach aggregates emissions from each of the many sources and is the most accurate method provided that the compilers can be confident that all sources have been identified and included and the relevant data are of good quality. It is clear that, where countries have

the data to prepare estimates using more than one methodology, a comparison of the results can throw light on differences which may be caused by omissions or double counts. Simmons (2000) suggests that countries that are able to prepare inventories using several methods should do so.

The existing tools for calculating GHG emissions are all based on determining the extent to which an activity takes place and applying appropriate emission coefficients. The applicability of each is determined by the nature of the emissions involved and the type of inventory being produced. Some of the commonest ones are described below:

2.4.1.1 The Greenhouse Gas Protocol

The GHG Protocol identifies, explains, and provides options for GHG inventory best practices. The GHG Protocol Corporate Standard provides standards and guidance for companies and other types of organizations such as governments and nongovernmental organizations preparing a GHG emissions inventory. It covers the accounting and reporting of the six greenhouse gases covered by the Kyoto Protocol—carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF₆).

Both business and other stakeholders benefit from converging on a common standard. For business, it reduces costs if their GHG inventory is capable of meeting different internal and external information requirements. For others, it improves the consistency, transparency, and understandability of reported information, making it easier to track and compare progress over time (WBCSD and WRI, 2001).

2.4.1.2 Intergovernmental Panel on Climate Change Inventory (IPCC)

The most common simple methodological approach is to combine information on the extent to which a human activity takes place (called activity data or AD) with coefficients which quantify the emissions or removals per unit activity. These are called emission factors (EF). For example, in the energy sector fuel consumption would be activity data, and mass of carbon dioxide emitted per unit of fuel consumed would be an emission factor. The basic equation can, in some circumstances, be modified to include other estimation parameters than emission factors. Where time lags are involved, due for example to the time it takes for material to decompose in a landfill or leakage of refrigerants from cooling devices, other methods are provided, for example first order decay methods.

2.4.1.3 ISO 14064

ISO 14064 Part 1 established a process for quantifying GHG emissions for the inventory. The first steps of this process are identification of specific emission sources within the operational boundaries as well as selection of an emission quantification methodology applicable for the sources identified. The next steps are the collection of data required by the methodology for the source and the identification of established emission factors for the data collected. Finally, the data and the emission factors are used to quantify emissions from individual emission sources. The emissions quantified for each source are then consolidated with the other sources within the operational boundaries, but ensuring that direct and indirect sources are kept separate (Wintergreen and Delaney, 2007). Within the primary text, the standard identifies three key aspects for developing a greenhouse gas

inventory for an organization. These are setting inventory boundaries, quantifying GHGs, and reporting GHGs.

2.4.1.4 Energy Star Portfolio Manager

The GHG accounting and tracking function in Energy Star's Portfolio Manager avails users the opportunity to record, track, and communicate the GHG emissions associated with the use of energy in their buildings (Energy Star, 2011). The Portfolio Manager Methodology accounts for all CO₂, CH₄, and N₂O emissions associated with the building's energy use. This inventory includes GHG emissions from both fossil fuel consumed on-site (referred to as direct emissions), as well as GHG emissions generated off-site at power plants that deliver heat, cooling or electricity to the building (referred to as indirect emissions).

To determine the direct emissions from on-site combusted fuels, Portfolio Manager utilizes a default fuel analysis approach. This simplifies calculation for the user by providing fuel-specific factors for heating value, carbon content, and carbon oxidation factor. Indirect emissions from district energy consumption (heating and cooling) use a similar approach. Indirect emissions from electricity consumption are determined through direct measurement by utility owners and operators, who report continuous emissions monitoring system data to EPA under several regulatory programs.

2.4.1.5 Common Carbon Metric

The Common Carbon Metric is the calculation used to define measurement, reporting, and verification for GHG emissions associated with the operation of building types of particular

climate regions. It does not include value-based interpretation of the measurements such as weightings or benchmarking. Even though it is not a building rating tool, it is consistent with methods for assessing the environmental performance of buildings used globally such as the World Business Council for Sustainable Development (WBCSD), World Resources Institute (WRI) GHG Protocol, and International Standards Organization (ISO) 15392:2008 Sustainability in Building Construction and general principles of ISO 14040/44:2006 on Life Cycle Assessment.

The Common Carbon Metric is applied to the specific inventory of the buildings under study. Such inventories are developed from a top-down or bottom-up approach, depending on the scope and goal of the investigation. Monitoring carbon mitigation measures on a regional or national scale require a top-down approach while assessing individual building projects require a bottom-up approach (UNEP SBCI, 2009).

2.4.2 Measurement of Carbon Dioxide (CO₂) Concentrations

Carbon dioxide is generally not considered as a health hazard at the usual indoor concentrations but a good indicator of building ventilation and indoor air quality is the concentration of CO₂ in a space (Washington State University Energy Program, 2013). There are different processes in buildings that emit CO₂ such as respiration and combustion of fossil fuels. The American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) recommend that the indoor concentration of CO₂ should not exceed 700ppm above outdoor air concentration which is typically between 300 and 400ppm. A typical outdoor level of 350ppm yields an indoor concentration of 1050ppm of CO₂. The WSU Energy Program (2013) observed that an elevated indoor CO₂ concentration is

directly related to the number of occupants in the building, the building's ventilation rate, and the CO₂ level in the outside air.

WSU Energy Program (2013) observed that the procedures to follow in measuring indoor CO₂ concentrations should include a check of the instrument calibration, adhering to the manufacturer's instructions regarding the equipment 'warm-up' period and operating conditions, measurement of the outdoor CO₂ concentration, repeating both the outdoor and indoor measurements a number of times and finding the average reading and not taking the readings too close to people. Indoor concentrations are also usually measured before the process.

2.5 GHG Emissions Inventory Development Process

A greenhouse gas inventory is a record of the amounts of GHGs emitted to or removed from the atmosphere over a period of time. Compiling a GHG inventory is a step-by-step process including the collection of data, estimation of emissions and removals, checking and verification, uncertainty assessment and reporting (Goodwin *et al*, 2006).

According to Simmons (2000) the completeness of the estimates depends upon the comprehensiveness of the methodologies used and the coverage of the activity data. When choosing the method for estimating emissions, it is important to ensure that all stationary combustion sources are included in the method used. Similarly, when data sources and fuels are been chosen, the inventory compilers must have a clear understanding of their uses and coverage so as to avoid any potential double counts or omissions.

Developing a GHG inventory generally relies upon measured or estimated data for a given base year or set of years. An inventory can be developed for different purposes, requiring different levels of sophistication. For instance, an inventory may simply be developed to estimate total GHG emissions for a state or region to understand baseline emissions. Alternatively, an inventory may be broken up into subcomponents, such as emissions by types of sources, or geographic levels (e.g., the county, city or neighbourhood) to develop a more detailed understanding of sources and potential mitigation approaches (U. S. Department of Transportation, 2014).

The general procedure for calculating GHG emissions from each emission source as given by ICF International (2011) is as follows:

- a. Determine the needed activity data (e.g., fuel consumption) for each emission source.
- b. Collect the activity data.
- c. Select appropriate emission factors based on the activity data.
- d. Calculate GHG emissions by gas (i.e., CO₂, CH₄, N₂O, HFCs, PFCs, and SF₆) by multiplying activity data by the appropriate emission factors.
- e. Convert emissions to metric tons CO₂-equivalent (MTCO_{2e}) using each GHG's GWP and sum to obtain total emissions.

2.5.1 GHG Accounting and Reporting Principles

According to UNEP-SBCI (2013) the generally accepted principles upon which the development of a GHG inventory is based are as summarized below:

Relevance: The GHG inventory should be developed in such a way that it would adequately reflect the GHG emissions of the entity and serve the decision making needs of users, both internal and external to the entity.

Completeness: The GHG inventory should be all encompassing. It should account for and report on all GHG emission sources and activities within the chosen inventory boundary. Any justifiable exclusion should be disclosed.

Consistency: Reliable methodologies should be adopted in the development of the inventory to permit meaningful comparisons of emissions over time. Changes to the data, inventory boundary, methods or any other relevant factors in the time series should be documented transparently.

Transparency: Transparency relates to the degree to which reported information is seen as being open and frank. Information is usually judged ‘transparent’ when it conveys a good understanding of the issues in the context of the reporting company, and when it provides a meaningful assessment of performance. An independent external verification is a good way of increasing transparency (WBCSD/WRI, 2001). The GHG inventory should address all relevant issues in a factual and coherent manner, based on a clear audit trail. A transparent report will provide a clear understanding of the data and allow for verification from a third party. In order to be transparent, the processes and procedures of collecting and calculating the data should be clearly documented and any assumptions made or limitations encountered should be disclosed as part of the report (UNEP-SBCI, 2013).

Accuracy: The GHG inventory should ensure that the quantification of GHG emissions is systematically neither over nor under actual emissions, as far as can be judged, and that uncertainties are reduced as far as practicable. In addition, the GHG inventory should achieve sufficient accuracy to enable users to make decisions with reasonable assurance as to the integrity of the reported information (WRI/WBCSD, 2007; Shil and Blue, 2007).

2.5.2 GHG Inventory Guidance Materials

According to ICF International (2011), there are two main types of GHG inventory guidance materials. These are the protocols and the guidelines.

- a. Protocols establish inventory design principles, such as how to define operational and organizational boundaries, guidelines for completeness, accuracy and transparency, and how to deal with uncertainty.
- b. GHG guidelines provide methods to estimate GHG emissions.

Both GHG protocols and GHG guidelines play an important role in providing uniform guidance for parties to prepare GHG emission inventories and some guidance materials provide both inventory design principles and methodologies.

2.5.3 Base Year Selection

A primary aspect of the emissions inventory process is the requirement to select a base year with which to compare current emissions (Oorbeck and Ly, 2009). A base year is a datum or reference point against which to measure GHG emissions performance over time. The UNFCCC (2008) described the baseline scenario as a plausible and consistent description

of how a system might evolve in the future in the absence of clearly defined new GHG mitigation policies.

Baseline scenarios are the counterfactual situations against which mitigation policies and measures will be evaluated. The baseline allows an entity to assess if overall GHG emissions are increasing or decreasing from year to year. The base year is usually selected to be the most recent year providing the most comprehensive data for inventory development (EPA, 2010; Oorbeck and Ly, 2009; ICF International, 2011).

In selecting a baseline year for an emissions inventory, it is good practice for entities to choose the earliest relevant year for which there is reliable data. In addition, baseline years may be mandated externally through state or regional reporting requirements. Another consideration in selecting a baseline year is whether to report by calendar year or by fiscal year. Calendar year reporting is consistent with the United Nations Framework Convention on Climate Change (UNFCCC) and several voluntary reporting programs, but fiscal years may make more sense for agencies if utility and other activity data are reported on a fiscal year basis (ICF International, 2011).

A baseline should not be considered as a forecast of what will happen in the future, since the future is inherently unpredictable and depends, in part, on planning and policy adoption. IPCC (2014) observed that the major drivers of anthropogenic GHG emissions are population size, level of economic activities, lifestyle, energy use, land use patterns, technology and climate policy. Assessments will typically require one or more baseline scenarios as baselines are highly uncertain over the long term and may prove controversial,

particularly in developing countries like Nigeria. UNFCCC (2008) also posited that baselines should not be a simple extrapolation of current trends. They should consider the possible evolution of activities that affect GHG sources and sinks, including consideration of:

- i. Macroeconomic and demographic trends;
- ii. Structural shifts in the economy;
- iii. Projections of the main GHG emitting activities and sinks;
- iv. The evolution of technologies and practices, including saturation effects and the likely adoption of efficient technologies that affect GHG emissions.

Recalculating the baseline inventory may be necessary to reflect changes that would compromise the consistency of reported emissions information such as considerable improvement in data quality in later years, availability of additional data, acquisition of an existing emission source, discovery of significant errors in the original inventory and changes in methodologies used to calculate GHG emissions.

The baseline scenarios identified by the World Meteorological Organization (N/Da) are the efficient baseline case and the business as usual baseline case.

- (i) Efficient baseline case assumes efficient and responsible use of resources and is also called mitigation scenario.
- (ii) Business as usual baseline case assumes that future developments will not change from those of the past. That is there will not be policy changes.

2.5.4 Forecast Years

Many factors can differentiate future emission levels from that of the present. Emission levels in the future can increase, for example, because of the rise in population or it could reduce because of the availability and adoption of cleaner technologies. While simple in concept, establishing an emissions baseline for the future, or "business-as-usual" forecast, can be challenging because it requires assumptions about energy use behaviour, types of technology and fuels, and other factors that affect emissions into the future that may not be easily predicted now (U.S. Department of Transportation, 2014).

The forecast for the community inventory according to FCM-ICLEI (2008) can be developed based on projected population growth or any other demographic projection. The method used to derive the forecast should be stated, and the data for the base year and any other inventory years should be shown, together with a calculation of the percentage change in each sector. Projected growth for individual sectors (e.g. residential, commercial, industrial, institutional) could be included if known, together with an estimate of the emissions likely to result from this growth, if a relevant indicator (e.g. square metres) is available.

Forecasts may be conducted to develop a baseline ("business as usual") projection or to analyze scenarios, such as different assumptions about future fuel prices and economic growth. If forecasts are required, then the approach used for the inventory and the forecasts normally should be compatible (e.g., using similar geographic boundaries, types of

approaches and inputs) to allow for direct comparisons to isolate changes or to accurately assess GHG reduction strategies.

2.5.5 Emission Scenarios

Emission scenarios are assumptions about the future that describe how the emission of GHGs might change between the years 2000 and 2100 (WMO, N/Da). Changes in emission levels are affected by a myriad of factors which vary from region to region and from time to time. The most prominent among these factors are economic growth rate, population growth rate, changes in technology, energy use pattern, lifestyle, land use patterns and environmental sustainability (IPCC, 2014 and WMO, N/Da). Future emissions of GHGs are very unpredictable to quantify and the scenarios are used as alternative images of how the future might play out. The scenarios are used in the analysis and modeling of climate change as well as assessment of impacts, adaptation and mitigation. The WMO (N/Db) has developed forty (40) different scenarios with different assumptions about future emission intensities and other driving forces. Each of these is open to different interpretations and probabilities of occurrence are not assigned.

Mitigation scenarios reflect a future in which explicit policies and measures are adopted to reduce the sources (or enhance the sinks) of GHGs, and are used to compare and evaluate GHG mitigation policies and measures against the counterfactual situation described in the baseline scenario. GHG mitigation scenarios should take into account the common but differentiated responsibilities of the Parties and their specific national and regional development priorities, objectives and circumstances. They should not simply reflect

current plans, but should, instead, assess what would be hypothetically achievable based on the goals of the scenario.

According to UNFCCC (2008) mitigation scenarios can be constructed in a number of ways. For example they may be based upon:

- i. An emission reduction target which, in turn, may be specified relative to the baseline, relative to emissions in a given historical year, or relative to an indicator such as emissions per capita or emissions per unit of gross domestic product (GDP);
- ii. The inclusion of all options up to a certain cost per unit of emissions reduction (equivalent to a carbon tax);
- iii. The inclusion of only “no regrets” options (i.e. options that have no positive cost per unit of emissions reduction);
- iv. Specific options or technologies, based on perceived technical or political feasibility.

2.5.6 Inventory Data Collection

Data can be defined as factual information (e.g. measurements or statistics) used as a basis for reasoning, discussion, or calculation. Data collection is the activity of acquiring and compiling information from different sources. Data collection according to Goodwin *et al* (2006) is a fundamental component of developing and updating a GHG inventory. Data collection procedures are necessary for finding and processing existing data, (i.e., data that

are compiled and stored for other statistical uses than the inventory), as well as for generating new data by surveys or measurement campaigns.

Other activities include maintaining data flows, improving estimates, generating estimates for new categories and/or replacing existing data sources when those currently used are no longer available. Goodwin *et al* (2006) opined that GHG inventory data collection involves these activities:

- I. Developing a data collection strategy to meet data quality objectives regarding timeliness, and also consistency, completeness, comparability, accuracy, and transparency
- II. Data acquisition activities including generating new source data, dealing with restricted data and confidentiality, and using expert judgement
- III. Turning the raw data into a form that is useful for the inventory

Woodfield (2016) pointed out that data providers might be reluctant in giving access to information either because it is confidential, unpublished, or not yet finalized. He went on to say that this is typically a mechanism to prevent inappropriate use of the data, unauthorized commercial exploitation, or sensitivity to possible imperfections in the data. Sometimes, however, the organisation simply does not have the resources required to compile and check the data. It is advisable, where possible, to cooperate with data providers to find solutions to overcome their concerns by:

- i. explaining the intended use to which the data will be put
- ii. coming up with a written agreement indicating the level to which the data will be made public

- iii. pointing out the possible increase in accuracy that can be gained through its use in inventories
- iv. cooperating to derive a mutually acceptable data sets
- v. giving credit/acknowledgement in the inventory to the data provided

2.5.6.1 Gathering Existing Data

Sources of existing data that can be used for GHG inventory development includes National Statistics Bureaus, relevant professionals, stakeholder organisations, IPCC Emission Factor Database, International experts, International organisations publishing statistics (e.g., United Nations, the International Energy Agency, OECD and the IMF), Reference libraries (National Libraries), Scientific and technical articles in environmental books, journals and reports, Universities, Web search for organisations and specialists, National Inventory Reports from Parties to the United Nations Framework Convention on Climate Change, etc. (Woodfield, 2016).

2.5.6.2 Generating New Data

It may be necessary to generate new data if representative emission factors, activity data or other estimation parameters do not exist, or cannot be estimated from existing sources. Generation of new data may entail measurement programmes for industrial process or energy related emissions, sampling of fuels for carbon content, land-use change and forestry sampling activities, or new census or surveys for activity data. Generation of new data is best undertaken by those with appropriate expertise (e.g., measurements carried out

by competent organisations using appropriately calibrated equipment or surveys and censuses by any national statistical authority). These activities are often resource intensive and are most appropriately considered when the category is crucial and there are no other options (Goodwin *et al*, 2006).

2.5.6.3 Adapting Data for Inventory Use

Greenhouse gas inventories require consistent estimates across time series and between categories. Gaps in the time series will exist when data are available at less than annual frequency and these will need filling. Time series data may need to be inferred to compile a complete annual estimate for the years between surveys, and for fore- and back casts (e.g., where estimates are needed for 1990 – 2004 and survey data are only available for 1995 and 2000). Other means of filling in data gaps and compensating for inconsistencies include incorporating improved data, compensating for deteriorating data and time series revision (Irving *et al*, 2006).

2.5.7 Stakeholders in Residential Greenhouse Gas Mitigation

The stakeholders of concern in GHG mitigation in buildings as identified by Takaoka (2011) are environmentalists, city governments, energy supply companies, building owners and users, real estate industry, service providers, financial agents and workers. The data generated from these groups will serve as input for the development of the mitigation policies.

2.5.8 Residential Energy Consumption

Adequate and uninterrupted supply of energy plays a fundamental role in the economic advancement as well as poverty eradication and security of any country. In Oyedepo (2012) uninterrupted energy supply is a vital issue for all nations today. Future economic growth crucially depends on the long-term availability of energy from sources that are affordable, accessible, and environmentally friendly. The standard of living of a given country can be directly related to the per capita energy consumption. The per capita energy consumption is a measure of the per capita income as well as a measure of the prosperity of a nation (Oyedepo, 2012; Ginley and Cahen, 2011).

Energy supports the provision of basic needs such as cooked food, a comfortable living temperature, lighting, the use of appliances, piped water, essential health care (refrigerated vaccines, emergency, and intensive care), educational aids, communication (radio, television, electronic mail, the World Wide Web), and transport. Energy also fuels productive activities including agriculture, commerce, manufacturing, industry, and mining. It has been projected in Wei *et al* (2011) that the average global energy consumption will reach 1.8% between the years 2005 to 2030. Growth rates are also expected to vary over time and between regions.

Energy consumption in residential buildings in Nigeria can be classified by the type of household appliances and by the source of energy. Common household sources of energy are purchased electricity, liquefied natural gas, coal, kerosene, wood and other types of biomass such as sawdust and dung. The major energy-consuming activities in Nigeria's

households are cooking, lighting, and use of electrical appliances. In Oseni (2012) household access to electricity services in Nigeria is low. About 60% of the population (over 80 million people) is not served with electricity and rural and semi-urban access to electricity is estimated to be about 35%.

2.6 Greenhouse Gas Mitigation Strategies

Energy consumption as well as the resulting CO₂ and other GHGs emissions can be significantly reduced through better harnessing of the available, cost-effective technologies in the operation of all types of buildings in the different climatic regions of the world. There are diverse array of energy end uses in the building sector. The buildings come in different sizes and types of shells which also call for use of different types of appliances and measures in their operations.

Numerous technologies and measures have been developed and implemented to reduce energy use in buildings, especially during the past two decades in Annex I countries. Harvey (2009) identified provision of high-performance envelope as the most important factor in the mitigation of CO₂ emissions associated with electricity consumption in buildings. This is even more critical in hot tropical climates like Nigeria where cooling energy demand in buildings can be very high during some seasons. This energy demand can be considerably reduced through passive incorporation of efficient measures into the design and construction of the buildings.

2.6.1 Setting the Mitigation Target

The U. S. Department of Transportation (2014) declared that there are many ways in which GHG mitigation targets can be set and the following are listed as some of such ways;

- i. Policy-based
- ii. Consensus-based
- iii. Analysis-based

The U. S. Department of Transportation (2014) further states that regardless of the approach adopted in setting the GHG emission reduction targets, it is important to first understand baseline conditions. For GHG emissions, the baseline should provide information on the key sources of emissions and factors affecting emissions. Baseline conditions will include past trends and current performance levels. In addition, it is important to conduct analysis to understand expectations for future performance.

2.6.2 Types of Greenhouse Gas Mitigation Options

Levine *et al* (2007) affirmed that GHG mitigation measures from buildings fall into one of three classes: reducing energy consumption and embodied energy in buildings, switching to low-carbon fuels including a higher share of renewable energy, or controlling the emissions of non-CO₂ greenhouse gases. Levine *et al* (2007) opined that numerous types of technologies that are commercially available and tested in practice can, to a large extent, reduce energy use while providing the same services and often considerable other benefits.

Likewise Fernandez *et al* (2005) has identified three categories of GHG mitigation options. Those that involve substituting GHG-producing activities with non-GHG producing activities are reduction approaches. Examples of GHG reductions are improvements to energy efficiency and prevention of deforestation. Sequestration begins with the capturing of GHGs that have already been produced (e.g. CO₂ re-absorption by plants during photosynthesis and capture of exhaust wastes from an industrial process). Sequestration is the storage of captured gases in a sink other than the atmosphere. Common examples of the sinks are forests and oceans.

Under the capture and use category, atmospheric GHGs are captured and then incorporated into products and energy sources that substitute for GHG-producing activities. For example, crops such as cassava and corn might be grown to be used for production of non-polluting ethanol, which then replaces the use of fossil fuels that emit GHGs. The various categories of GHG mitigation options as identified by Fernandez *et al* (2005) are as summarized in Table 2.3.

Table 2.3: The Categories of Mitigation Options

Reductions	Sequestration	Capture and Use
Industrial process modifications	Forest sequestration	Methane capture
Renewable energy transition	Agricultural sequestration	Biomass to energy
Demand side efficiency improvement	Geological sequestration	Biomass to product
	Ocean sequestration	
	Mineral carbonation	

Source: Fernandez *et al*, 2005

2.6.3 Strategies for Residential CO₂ Mitigation

It has been observed that a significant means of reducing GHG emissions in the building sector involves more rapid deployment of technologies aimed at reducing energy use in building equipment (appliances, heating and cooling systems, lighting and all plug loads, including office equipment) and reducing heating and cooling energy losses through improvements in building thermal integrity, urban design and land-use planning that facilitate lower energy-use patterns and reduce urban heat islands, fuel switching, improving the efficiency of heating and cooling systems, using more sustainable building techniques, ensuring correct sizing, installation and operation of equipment as well as using building energy management systems (BEMS) (RIBA, 2009 and PEW CENTER, 2009).

The various measures identified from existing literature for mitigation of climate change from energy use in buildings can be grouped into three broad categories namely proper building design and orientation, energy efficient services design and behavioural modifications by the households (Minor and Bivens, 2002; Levine *et al*, 2007 and Cam, 2012). PEW CENTER (2009) corroborated this view in its statement that emission reduction from buildings can be achieved by reducing energy consumption through improved building design, increased energy efficiency and conservation (through correct services design), and other mechanisms that reduce energy demand in buildings (behavioural changes).

2.6.3.1 Building design

Minor and Bivens (2002) observed that one path to reduced buildings energy consumption and decreased GHG emissions is obviously through increased HVAC and lighting energy efficiency. According to them this can be achieved by carefully planning the initial building design to reduce the need for HVAC equipment. Some deliberate measures identified towards achieving this target are reducing unwanted heat gain into the buildings, harnessing natural ventilation and cooling techniques, expanding occupants comfort envelope, and properly sizing and controlling air conditioners and other cooling equipment.

UNEP SBCI (2009) posited that the rate at which energy is gained or lost through the physical structure of the building (the building envelope), and the rate at which energy is used to meet the needs and physical comfort of the occupants are the two most important factors to consider in designing energy efficient buildings. The form and fabric of buildings can be designed to do as much of the work of environmental modification as possible to minimize the demand on services such as heating and lighting (RIBA, 2009). Levine *et al* (2007) pointed out that some key decisions designers can take early in the design stage of a building that can greatly influence the subsequent opportunities to reduce building energy use and CO₂ emissions include an appropriate building form, orientation, self-shading, height-to-floor-area ratio and decisions affecting the opportunities for and effectiveness of passive ventilation and cooling. Specific design measures identified by Levine *et al* (2007) for reduction of energy consumption and CO₂ emission from cooling loads include the following:

- (i) orienting a building to minimize the wall area facing direct solar radiation from east or west;
- (ii) closely grouping buildings together to provide some degree of self-shading (as in many traditional communities in hot dry climates);
- (iii) using building materials that are highly reflective;
- (iv) providing adequate insulation as dictated by the location of the building;
- (v) provision of fixed or adjustable shading as may be appropriate;
- (vi) using selective glazing with low solar gain and high daylight transmission on windows and minimizing window area to what is reasonably necessary (particularly on east- and west-facing walls which are exposed to solar radiation for long times of the day); and
- (vii) utilizing thermal mass to minimize daytime interior temperature peaks

2.6.3.2 Services design

Building services design should be done such that they are as efficient as possible, and use fuels with low CO₂ emissions factors (RIBA, 2009). It has been pointed out by Minor and Bivens (2002) that building lighting energy can be reduced by 75% or more by adopting a systems approach and using natural and energy-efficient lighting such as compact fluorescent lamps (CFL) and light emitting diodes (LED). RIBA (2009) also observed that careful selection of efficient lights and appliances can halve the CO₂ emissions associated with these energy end uses.

Similarly provision for adequate ventilation can reduce the need for mechanical cooling systems and consequently emission of CO₂. Green building or sustainable building systems is one way through carbon emissions from buildings can be significantly reduced or avoided altogether. These systems combine design and technology, usually renewable energy systems, to achieve very low or even zero carbon emissions. For example, passive houses are houses which maintain a comfortable interior climate without active heating and cooling systems. Their additional energy requirements may be completely covered using renewable energy sources such as wind and solar energy (RIBA, 2009).

Levine *et al* (2007) observed that the design strategies for energy-efficient buildings include reducing loads, selecting systems that make the most effective use of ambient energy sources and heat sinks and using efficient equipment and effective control strategies. They also pointed out that an integrated design approach is required to ensure that the architectural elements and the engineering systems work effectively together. Levine *et al* (2007) pointed out that lighting energy use can be reduced by 75 to 90% compared to conventional practice through the following practices:

- (i) use of daylighting with occupancy and daylight sensors to dim and switch off electric lighting;
- (ii) use of the most efficient lighting devices available; and
- (iii) use of such measures as ambient/task lighting.

Levine *et al* (2007) asserted that utilization of systems approach to building services design will enable the visualization of a building as an entire system as against individual units and

this can lead to entirely different design solutions that can result in new buildings that use much less energy but are no more expensive than conventional buildings. They further stated that the systems approach in turn requires an integrated design process (IDP), in which the building performance is optimized through an iterative process that involves all members of the design team from the beginning. They identified the steps in the most basic IDP for a commercial building to include:

- (i) Selecting a high performance envelope and highly efficient equipment that is properly sized;
- (ii) Incorporating a building energy management system that optimizes the equipment operation and human behaviour, and
- (iii) Fully commissioning and maintaining the equipment.

2.6.3.3 Behavioural modifications

The energy use of a building also depends on the behaviour and decisions of occupants and owners especially when the lighting, cooling and ventilation are manually controlled. Studies have also shown significant variations of energy use in similar buildings with different occupants (Levine *et al*, 2007). For example households can change from energy and carbon intensive cooking methods by adopting one or more of the following efficient measures to reduce domestic cooking energy needs:

- a. improved efficiency of biomass stoves;
- b. improved access to clean cooking fuels, both liquid and gaseous;

- c. access to electricity and low-wattage and low-cost appliances for low income households;
- d. non-electric options such as solar cookers;
- e. efficient gas stoves; and
- f. small electric cooking equipment such as microwaves, electric kettles or electric frying pans.

PEW CENTER (2009) observed that reducing light use can be achieved by behavioural changes which involves individual commitments to only keep on the lights that are in use or by using motion sensors, occupancy sensors, time sensors, and photo sensors to automatically ensure that lights are only on when they are needed.

2.7 United Nations Framework Convention on Climate Change (UNFCCC)

The United Nations Framework Convention on Climate Change (UNFCCC) is an international environmental treaty that aims to address the threat of anthropogenic (human induced) climate change at an international level. It came into existence in 1994 and has been ratified by 192 countries (UNFCCC, 2008). The framework seeks the “stabilization of GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system” (Article 2 of the Convention). The Conference of the Parties (COP) is the highest decision-making authority of the Convention.

2.7.1 Parties to the Convention

Parties to the UNFCCC are expected to “take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects”. Parties have “common but differentiated responsibilities” based on their national circumstances.

Each Party is committed to:

- i. Gathering and sharing information on GHG emissions, national policies and best practices
- ii. Formulating strategies for addressing GHG emissions and adapting to the expected impacts;
- iii. Cooperating in preparing for adaptation to the impact of climate change.

The UNFCCC differentiates between three different groups of Parties:

- a. Annex I comprises those countries that were members of Organisation for Economic Cooperation and Development (OECD) in 1992 as well as countries with economies in transition (EIT);
- b. Annex II comprises the OECD members of Annex I;
- c. Non-Annex I Parties are primarily the developing nations.

2.7.2 The UNFCCC Guidelines on Mitigation Assessment

Under the UNFCCC, each Party has to report its GHG emissions and its mitigation and adaptation strategies in its national communications. More specifically, each Party has to submit to the COP a GHG inventory with information on its emissions by sources and

removals by sinks of all GHGs not controlled by the Montreal Protocol. Furthermore, each Party has to submit a mitigation plan detailing the steps taken or envisaged by the Party to implement the Convention.

2.7.3 Intergovernmental Panel on Climate Change (IPCC)

The Intergovernmental Panel on Climate Change was created in 1988. It was set up by the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP) to prepare, based on available scientific information, assessments on all aspects of climate change and its impacts, with a view of formulating realistic response strategies. The initial task for the IPCC as outlined in UN General Assembly Resolution 43/53 of 6 December 1988 was to prepare a comprehensive review and recommendations with respect to the state of knowledge of the science of climate change; the social and economic impact of climate change, and possible response strategies and elements for inclusion in a possible future international convention on climate. The role of the IPCC involves assessing on a comprehensive, objective, open and transparent manner the scientific, technical and socio-economic information relevant to understanding the scientific basis of the risk of human-induced climate change, its potential impacts and options for adaptation and mitigation (The Nobel Foundation, 2007).

2.8 Greenhouse Gas Mitigation Assessment

According to the UNFCCC (2008) a mitigation assessment is a national-level analysis of the various technologies and practices that have the capacity to mitigate climate change. Typically, mitigation assessments include the development of one or more long-term

mitigation scenarios. A mitigation scenario is a quantified projection of how future GHG emissions can be reduced relative to one or more baseline scenarios. A baseline scenario characterizes the likely evolution of GHG emissions in the absence of new, specific policies to reduce GHG emissions. A mitigation assessment, therefore, involves creating both baseline and mitigation scenarios.

UNFCCC (2008) observed that it is important to note that, for many Parties, mitigation does not necessarily imply an absolute reduction in emissions in relation to a given base year, rather it implies a reduction relative to what emissions would otherwise have been in the future in the absence of specific GHG mitigation action, that is, relative to a counterfactual baseline scenario.

2.8.1 Steps in Mitigation Assessment

Any mitigation assessment should focus on clearly defined objectives and emphasize implementation. According to the UNFCCC (2008) the basic steps will depend on the objectives and the scope of the assessment, but should include the following:

- i. Collection of the needed data;
- ii. Assembling base year or historical data on activities, technologies, practices and emission factors;
- iii. Calibrating base year energy and emissions calculations with available standardized statistics such as national energy balances and/or national emissions inventories;
- iv. Preparing baseline scenarios;

- v. Screening mitigation options;
- vi. Preparing mitigation scenarios and sensitivity analyses;
- vii. Assessing the social, economic or environmental impacts;
- viii. Developing an overall mitigation strategy;
- ix. Preparing reports.

2.9 Conceptual Framework

A conceptual framework is used in research to outline possible courses of action or to present a preferred approach to an idea or thought. When no theory exist that fits the concepts the researcher wishes to study as is the case in this study, the researcher may construct a conceptual framework that can be used to describe and explain the relationships of the concepts (Creswell, 2014). Mehta (2013) identified the steps involved in the development of a theoretical framework or conceptual framework as follows:

- a. Selection of concepts
- b. Identification of the interrelationships among the selected concepts
- c. Formulation of definitions which include conceptual and operational definitions.
Conceptual definition conveys the general meaning of the concept whereas operational definition delineates the procedures or operations required to measure the concept.
- d. Formulation of the theoretical rationale

2.10 Concepts related to GHG emission reduction

The concepts related to reduction of GHG emissions from buildings and upon which this study is built include appliance energy consumption, energy audit, estimation of emission, emission factor, possible reduction in emission and environmental sustainability.

2.10.1 Energy Consumption

The U.S. Department of Energy (2016) identified the various ways to estimate an appliance's electrical energy consumption to include:

- a. Reviewing the energy guide label which estimate average energy consumption by the appliance,
- b. Using an electricity or other type of energy consumption meter to get readings of how much electricity or energy an appliance is using,
- c. Calculating annual energy consumption and costs using the formulas, and
- d. Installing a whole house energy monitoring system.

The study adopted the third method which involves calculation of the energy consumption by appliances using formulae. The U.S. Department of Energy (2016) gave the following formulae for calculating energy consumption by appliances.

Daily energy consumption

$$= \text{Wattage} \times \text{Hours of use daily} \div 1000 \text{ --- 2.1}$$

Annual energy consumption

$$= \text{Daily consumption} \times \text{number of days used per year} \text{ --- 2.2}$$

of its rate of energy consumption, and the number of hours it operates in a 24-hour period. An energy audit, or review, is an investigation of all facets of an organisation's historical and current energy use with the objective of identifying and quantifying areas of energy wastage within the organisation's activities. An energy audit establishes the baseline for any improvements in an organisation's energy use. It provides a comprehensive and systematic method for targeting cost effective efficiency gains (Energy Management Association of New Zealand, 2015).

2.10.3 Estimation of Emissions

World Resources Institute, WRI, (2006) gave the four main methods for quantifying GHG emissions as emission factors-based approaches, mass (material) balance measures, predicative emission-monitoring systems (PEMS), and continuous emission-monitoring systems (CEMS). GHG emissions are quantified by either direct measurement or calculations. Directly measuring GHG emissions by monitoring their concentration and flow rates from a stack is not common and is generally limited to stationary combustion sources. GHG emissions according to WRI (2006) are more often derived from a calculation-based approach, using either a mass balance basis specific to a source or process or, more commonly, documented emission factors. These factors are calculated ratios relating GHG emissions to a measure of activity at an emissions source, for example, a vehicle's carbon dioxide (CO₂) emissions per mile driven.

The general equation for emissions estimates as given by WRI (2006) is as follows:

$$E = A \times EF \text{ ----- 2.4}$$

Where E = emissions

A = activity data (e.g., fuel consumed, material input, throughput, or production output)

EF = emission factor (usually the weight of the pollutant or the unit weight, or the volume or duration of the activity, e.g., tons CO₂ or tons of coal).

2.10.4 Emission Factor (EF)

The WRI (2006) defines an emission factor as a unit (e.g., a ton) of a greenhouse gas (e.g., CO₂) produced per unit of activity (e.g., miles driven). UNFCCC (2014) defined it as the average emission rate of a given GHG for a given source, relative to units of activity. In other words an emission factor is a unit (e.g., a ton) of a greenhouse gas (e.g., CO₂) produced per unit of activity (e.g., miles driven). Emission factors may be based on data collected, averaged, or aggregated differently depending on the intended use of the emission factor and the availability of the data. Emission factors are expressed in kilograms (kg) or metric tonnes (t) of GHG emissions per unit of consumption activity. Typically, the factors for a given category of activity – for example, building energy consumption – are expressed in common units to enable comparison across different fuel types. Carbon dioxide equivalent (CO₂e) is the standard unit for measuring and comparing emissions across GHGs of varying potency in the atmosphere (British Columbia Ministry of Environment, 2013).

The adoption of the EF method in this study is substantiated by the WRI's proclamation that emission factors tend to more accurately estimate CO₂ emissions and less accurately estimate CH₄, N₂O, SO₂, NO_x, and other criteria air emissions, whose estimates are affected by the specific characteristics of the fuel and the reporter's operating conditions and equipment. Emission factors also are generally more accurate for stationary and mobile combustion sources and less for process, fugitive emission, and waste sources, in which differences in the entity's practices and equipment may significantly change the resulting emissions (WRI, 2006).

2.10.5 Reduction in Emission

The quantities of CO₂ emitted can be significantly reduced by households through energy efficient practices and adoption of sustainable energy sources for their needs. One of the ways of reducing CO₂ emissions from buildings is the installation of highly efficient electrical appliances and lighting and behavioural measures such as turning off lights or turning down thermostats. The amount of reduction in emission can be estimated by finding the difference between the baseline emissions attributable to the various household appliances and the mitigation or efficient case emissions. For example, the amount of reduction in emissions from lighting can be calculated by first obtaining the emissions resulting from conventional and inefficient light bulbs and practices and doing same for the energy efficient fittings and practices. The difference between the two will give the possible emission reduction from lighting. Possible emission reductions from other household energy uses can be estimated in a similar manner.

2.10.6 Environmental Sustainability

The overwhelming reliance on fossil fuels has made the current patterns of energy use environmentally unsustainable (Ahuja and Tatsutani, 2009). This is particularly the case in Nigeria where approximately 71.5% of available energy is from unsustainable sources (i.e. fossil fuels). In view of the negative effects of energy generation from these sources, the study attempted assessing their sustainability. One way of measuring the environmental sustainability is by measuring CO₂ concentration. According to the United Nations (2011) household energy use, energy consumption/capita and share of renewable energy sources in total energy consumption are some measures of environmental sustainability.

There are different indicators used for measuring sustainability and one important aspect identified by Moldan *et al* (2012) for measuring environmental sustainability is by setting targets and then “measuring” the distance to a target to get the appropriate information on the current state or trend. The U.S. Department of Transportation (2015) declared that sustainability is measured by assessing performance of social, environmental and economic principles. It also states that one method of measuring the sustainability of highways is to assess a program or a project against existing best practices. In the same vein it can be presumed that the environmental sustainability of household energy consumption can be assessed by comparing against existing best practices.

2.10.7 Behaviour of Households

The mitigation of CO₂ emissions from energy consumption activities at home would require an understanding of the pattern of energy use by the households. This can be achieved through knowledge of the various appliances owned and their frequencies of use. The framework considers the two sources of energy for use in buildings namely grid electricity and energy generated on site by the households by burning biomass and fossil fuels. The amount of CO₂ emitted can be calculated by estimating the quantities of each of the two energy sources. An understanding of the behaviour of the households can reveal vital insights into how modifications in such behaviours can reduce emission of GHGs.

Other stakeholders like the building owners, built-environment professionals, governments and non-governmental organizations also have important roles to play in mitigation of CO₂ from buildings. The relationships between the various concepts of the study are as presented in Figure 2.1.

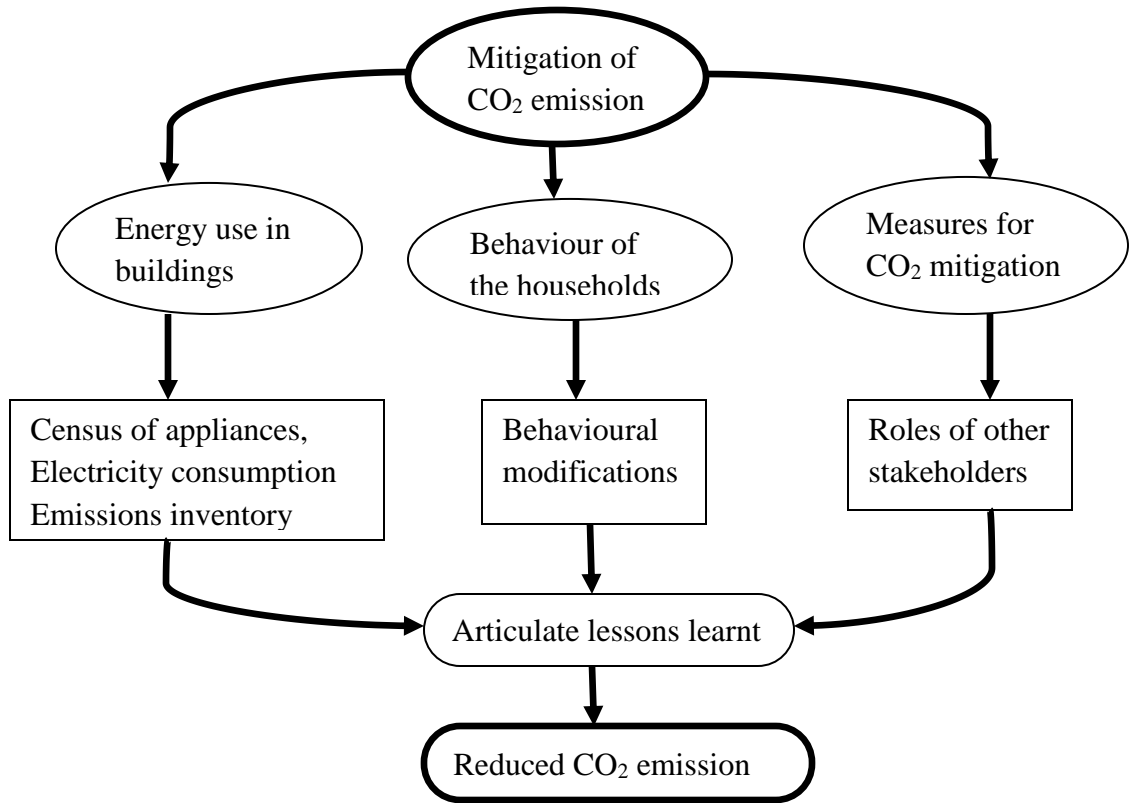


Figure 2.1: Conceptual Framework for the Study

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

3.1 The Approach to the Study

The work involves the collection of quantitative data through calculations of CO₂ emissions using emission factors and measurements of concentration of CO₂. The direct on-site emissions and indirect emissions were calculated using the amount of fuel consumed for the various activities and electricity consumption data generated from the field survey respectively.

The survey yielded data on the energy consumption patterns of the households; that is the common household energy use equipment, rating and frequency of use of the equipment, fuel types used by households for various activities as well as any effort on the part of the households towards achieving efficient use of energy. The amount of CO₂ generated from the various energy use activities were calculated using the information obtained from the survey of the households. Indoor and outdoor concentrations of CO₂ were also measured to see the extent to which they agree with the recommendations on acceptable limits of concentration of the gas and also observe how they compare with the global average.

3.2 The Study Area

The study area is Kaduna metropolis which is the capital of Kaduna state. Kaduna was founded in 1913 by the British in 1913. It comprises of four local government areas (LGAs) namely Kaduna North, Kaduna South and parts of Chikun and Igabi. It lies within the

central area of the Northern part of Nigeria along the Kaduna River, which is a major tributary of the River Niger. It served as the capital of the former Northern Region from 1954 to 1967 and has remained a focal point of Northern politics and economy. Since the late 1950s, Kaduna Metropolis has become a major industrial, commercial, and financial hub for the northern states of Nigeria (Encyclopedia Britannica, 2014). Figure 3.1 shows the 23 LGAs of Kaduna state.



Figure 3.1: Local Government Areas in Kaduna State

Source: National Population Commission, 2009

3.2.1 Geography and Population of the Area

Kaduna Township is advantageously located within the state; it is located near the geographical centre and benefits from close proximity of a river running horizontally across the territory. Kaduna State generally experiences a tropical continental climate with two distinct seasonal climates; dry and rainy seasons. The wet season occurs between May to October and the dry season thereafter to the late April of the following year.

The metropolis has an area of 8797.757 square kilometres (NPC, 2009a). The population of Kaduna metropolis in 2006 was one million five hundred and seventy thousand, three hundred and thirty one (1,570,331). Table 3.1 is a summary of the population of Kaduna municipality according to the 2006 National Population and Housing Census (NPC, 2009a). The average household size is five people and the population growth rate is estimated to be 3% per annum. Applying this growth rate to the figure for 2006 and assuming that all other factors are constant, the present population of Kaduna metropolis is estimated to be one million, nine hundred and eighty nine thousand, two hundred and forty eight (1,989,248).

Table 3.1: Local Governments and Population of Kaduna Metropolis

Local Government	Land Size (km ²)	Male	Female	Both Sexes
Chikun	4800.502	187433	184839	372272
Igabi	3860.97	217414	213339	430753
Kaduna North	74.92	187075	177500	364575
Kaduna South	61.365	204969	197762	402731
Total	8797.757	796891	773440	1570331

Source: NPC, 2009a

3.2.2 Socio-Economic Profile of the Area

Kaduna state as a whole is a centre of learning for northern Nigeria particularly and Nigeria as a whole. This is because of the presence of prominent national institutions in the state particularly the metropolis. The most notable of these institutions are the Nigerian Defense Academy, Federal Training Centre, National Board for Technical Education, National Primary Education Commission and the National Eye Centre. The private sector also plays an important role in the provision of formal and non-formal education in the city.

Besides the public and private formal sectors of schooling, there are a number of other forms of non-formal basic education systems targeted at specific population groups. Non formal education in Kaduna metropolis and other parts of the state comprises basic literacy and post literacy programmes. Some literacy centres include Islamic schools, mass literacy continuing education centres and other programmes offered by NGOs.

Kaduna belongs to the league of top commercial cities in Nigeria, second only to Kano in the North. Kaduna state ministry of land, survey and country planning (2015) declared that it is the fifth largest city in Nigeria behind Lagos, Kano, Ibadan and Abuja. The top industrial establishments of Kaduna included textiles, furniture, automobiles (Peugeot Automobile Nigeria), associated fabrication industries, Nigerian Breweries and the Nigerian National Petroleum Corporation (NNPC) refinery. Kaduna has an International Trade Fair Complex along Zaria road in which it hosts annual trade fairs. According to Ndabula *et al* (2014) Kaduna was the second most industrialized city in Nigeria after Lagos

in the 1970's even though there has been a significant decline in this economic fortune of Kaduna in the last two-three decades.

Most manufacturing activities are concentrated towards the southern end of the city. The town's cotton-textile industry used to be Nigeria's largest and unarguably among the largest in Africa. The food and beverage industry produces beer, soft drinks, baked goods, and processed meat. Light manufactures include leather goods, plastics, ceramics, pharmaceuticals and furniture in addition to the presence of several printing and publishing organizations. Steel and aluminum products, construction materials and electrical cables and motors are also produced in the town. An automobile assembly plant and an oil refinery also operate in Kaduna (Encyclopedia Britannica, 2014).

Kaduna is also a centre for the construction industry with the presence of many indigenous and foreign companies. The town like some other big towns in the north serves as a collecting point for cotton, peanuts (groundnuts), shea nuts, and hides and skins. There is also a considerable local trade in other agricultural commodities like beans, millet, maize, kola nuts, goats, poultry, and cattle.

3.2.3 Clusters in Kaduna Metropolis

Stanley (2011) divided Kaduna metropolis into twelve clusters. This study adopted that division without any changes. The clusters are:

- A. Sabon Tasha, Television and Ungwan Sunday
- B. Ungwan Romi and Gonin Gora

- C. Barnawa and Narayi
- D. Nasarawa and Kakuri
- E. Ungwan Rimi and Kabala Doki
- F. Gabasawa (Kaduna Central)
- G. Tudun Wada
- H. Bakin Ruwa, Kabala West and Ungwan Muazu
- I. Kurmin Mashi, Abakpa, Ungwan Kanawa and NDA
- J. Ungwan Sarki, Malali and Badarawa
- K. Kawo and Hanyin Banki
- L. Mando and Afaka

The clusters are henceforth identified by the first neighbourhood in the list above. Figure 3.2 is a map of Kaduna metropolis showing the four local government areas and the neighbourhoods making up the clusters. Kaduna state ministry of land, survey and country planning (2015) has divided the residential areas within the city into three based on concentration of population as high density, medium density and low density residential/mixed use areas. The high density neighbourhoods are Tudun wada, Sabon gari, Kawo, Barnawa, Narayi, Ungwan Kanawa and Abapka. Kakuri, Badarawa, Malali, Gabasawa, Ungwan Rimi, Badiko, Makera, Rigachikun, Kabala and Gwanin Gora are classified as medium density neighbourhoods while the low density areas are Nasarawa, Ungwan Television, Rigasa and Afaka.

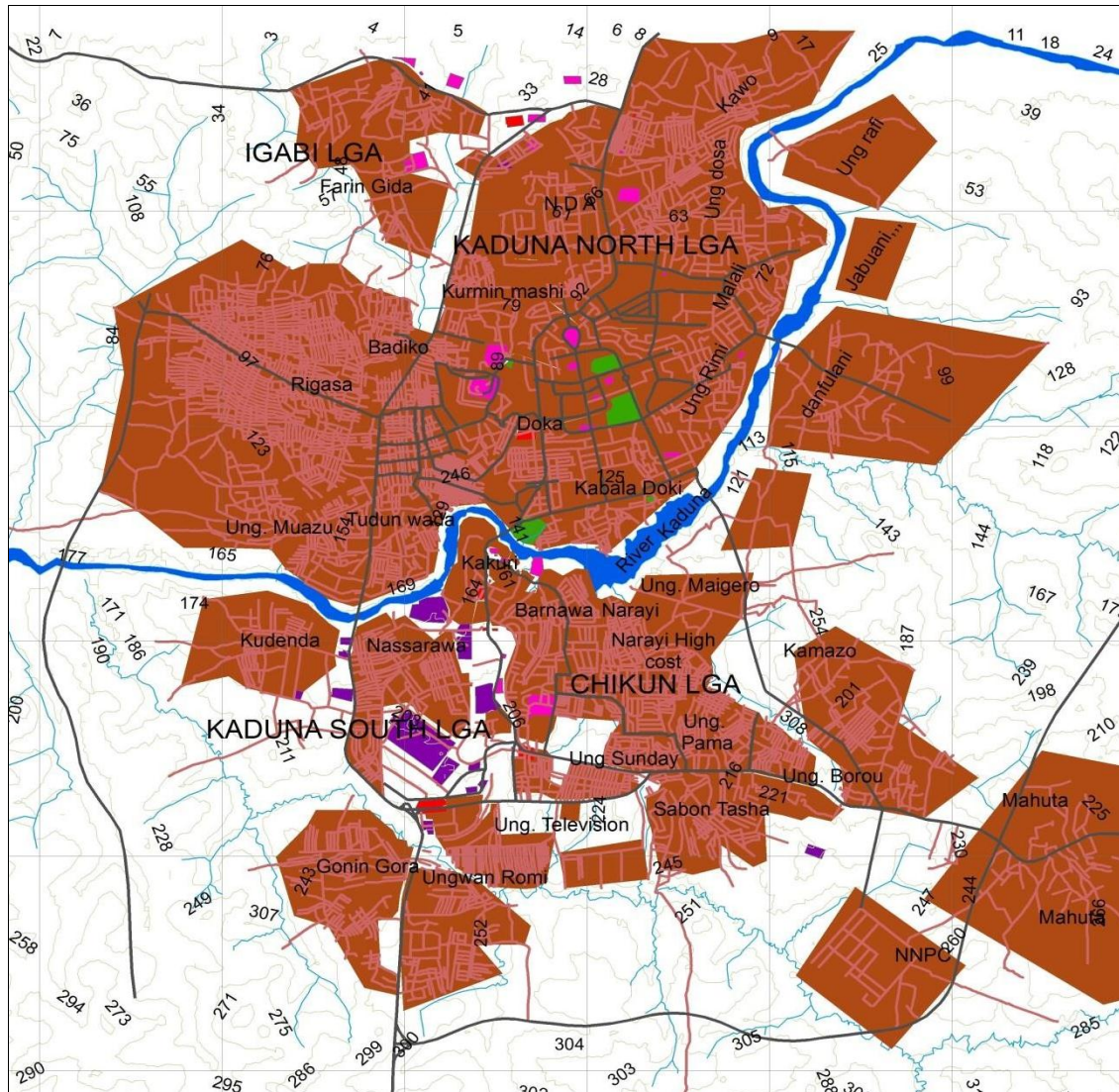


Figure 3.2: The local governments and the neighbourhoods in Kaduna metropolis

Source: Satellite imagery 2013, SRTM DEM 2013, GIS Analysis 2014

3.3 Collection of Data

The study collected mainly quantitative data. Data was collected for 2015 as the base year and forecasts were made for 2020, 2035 and 2050 for the business as usual (BAU) and mitigation scenarios for comparisons. IPCC (2014) observed that assessments of GHG emissions for the purpose of making forecasts will typically require one or more baseline

scenarios as baselines are highly uncertain over the long term and may prove controversial, particularly in developing countries. In view of this two baseline scenarios have been developed in this study. They are as follows:

- A. Forecast based on 1.6% annual global growth rate in all GHG emissions over the past three decades as observed in UNFCCC (2009). It has also been observed in the UNFCCC (2009) that the emission of CO₂ from the use of fossil fuels has been growing at the rate of 1.9% per year. This is called Case A.
- B. Forecasts based on the estimated population growth rate of Nigeria from the 2006 National population and housing census data (NPC, 2009a). The estimated growth rate is 3% per annum. It has been assumed that this growth trend will continue into the future and emissions of CO₂ will follow this trend. This is called Case B.

IPCC (2014) and FCM-ICLEI (2008) identified population growth rate and other demographic features of a community as some of the main factors that drive their GHG emissions.

The alternative policy scenario emissions were based on 50% reduction on the BAU scenario emission by the year 2050. The BAU scenario emissions were calculated from the baseline emissions from 2015. The emissions for the intermediate years of 2020 and 2035 in the alternative policy scenarios were interpolated from 2015 and 2050.

3.4

Sources of Data for the Study

The data for the study was sourced in two ways as follows:

3.4.1 Secondary sources

Census figures for both humans and housing stock for Kaduna was obtained from the National Population Commission (NPC). The National Bureau of Statistics (NBS) also provided additional information about the housing types. The NPC provided data about the housing population of the local government areas in the metropolis. The system of grouping the residential housing units here is modeled after the 2006 National Population and Housing Census Tables (NPC, 2009b and UNFPA, 2009) which provided the data for that year and the figures for the baseline year were projected from these.

3.4.2 Primary sources

A structured questionnaire was used to generate the data. The data that was sought through the questionnaire included information about the buildings and the buildings' energy consumption profile. Data for calculation of energy consumed in the buildings was gotten from the responses to the questionnaires distributed to the households that participated in the study. There are two types of this data namely data for calculation of direct emissions and data for calculation of indirect emissions.

3.4.2.1 Data for Calculation of Direct Emissions

The predominant direct emissions from the households are from the activities listed below:

- a. Operation of generators to produce electricity for use by the household when the grid supply is off. The emissions here were estimated by multiplying the quantity of fuel consumed by the relevant emission factor (3186.30kg/tonne). The quantity of petrol consumed was estimated in litres and later converted to kilograms (kg) by applying the density of petrol which was obtained from Soman (2011) to be 740kg/m³.
- b. Use of gas powered cookers for food preparation. The commonest gas used is the Liquefied Petroleum Gas (LPG). The quantity of gas used was multiplied by the emission factor (2984.63kg/tonne) to get the CO₂ emission from this activity.
- c. Use of kerosene stoves for cooking. The amount of kerosene used was multiplied by the kerosene emission factor (3149.22kg/tonne) to get the emissions from this activity. The quantity of kerosene consumed was also estimated in litres and converted to mass (kg) by applying the density (810kg/m³) as given by Soman (2011).
- d. Cooking with biomass (wood and its derivatives). The quantity of wood used was multiplied by the emission factor for wood (1747.20kg/tonne) to get emissions due to the use of wood. There exists literature on the average quantity of fuel wood used by households and also per capita on daily basis. This study adopted the daily per capita consumption of 0.776kg in Kaduna state as was determined by Zaku (2013). The average consumption by each household is 4.66kg on daily basis.

3.4.2.2 Data for Calculation of Indirect Emissions

The data here is used for the estimation of CO₂ emissions due to the use of grid electricity generated from fossil fuels. The data includes information about the buildings and electrical appliances and their frequencies and durations of use. The quantity of electricity consumed by operating the appliances is multiplied by the emission factor to get the quantity of the emissions. The estimated quantity of electricity was reduced by 28.5% corresponding to the quantity generated from hydroelectric dams (BPE, 2011) which do not emit CO₂ as it is a renewable source of electricity. Information about the buildings includes the following:

- i. Reporting period
- ii. Building type
- iii. Buildings gross floor area and
- iv. Total number of full-time occupants

3.5 The Data Collection Instrument

The instrument used for the collection of data is a structured questionnaire. The questions asked are closed ended with options from which respondents were requested to select the ones that apply to them. The questions are about the type of appliances possessed, average daily duration of use, types of fuel used for powering the appliances and any measures being taken to avoid wasteful use of energy. The answers to these questions provided the activity data on which the relevant emission factors were applied to get the emissions resulting from the activities.

The questionnaire is divided into sections including characteristics of the buildings, building energy consumption data, onsite energy generation and consumption and energy use behaviour and behavioural adaptations. The characteristics of the building has to do with information about the building including the location, size, age, type of the building as well as the number of full time residents. The section on energy consumption in buildings is subdivided into specific energy use activities like ventilation, cooling, food preparation and cooking, lighting, entertainment, laundry, sanitation and hygiene and other household appliances. This was done to ease sorting and analysis of the data. A sample of the questionnaire has been attached as an appendix (Appendix 1).

3.6 Sampling

3.6.1 Sampling Techniques

The study adopted the division of Kaduna metropolis into twelve clusters as was done by Stanley (2011). This is to ensure a fair representation of households in all the neighborhoods of the city.

The buildings studied from each cluster were determined using convenience sampling which involves drawing samples that are both easily accessible and willing to participate in the study. It should be noted here that although convenience sampling was used to select the studied households, the houses were selected in such a way as to accommodate as much as possible the diversities in the households.

3.6.2 Sample Size

The equation given by Yamane (1967) in Israel (2013) was used to determine the appropriate sample size. The equation is as follows:

$$n = \frac{N}{1 + N(e)^2} \text{----- 3.1}$$

Where

n is the sample size;

N is the population size and

e is the level of precision or sampling error. It is the range in which the true value of the population is estimated to be. This range is often expressed in percentage points ($\pm 3\%$, $\pm 5\%$, $\pm 7\%$ or $\pm 10\%$).

According to the 2006 National Population and Housing Census in Nigeria, the Kaduna metropolis has a total of three hundred and six thousand, five hundred and eight (306508) regular households which comprise of houses on separate stands or yards, traditional/hut structures, flats in blocks of flats, semi-detached houses, let in houses, informal/improvised dwellings and others (this refers to houses belonging to none of the listed groups). Table 3.2 shows the local governments that constitute Kaduna metropolis with their housing populations.

Table 3.2: Population of Houses in Kaduna Metropolis

Local Government	Number of Houses
Chikun	76289
Igabi	77243
Kaduna North	71283
Kaduna South	81693
Total	306508

Source: National Population Commission, 2009b

Assuming a precision level of 7% (0.07) and substituting into equation 3.1, the sample size is obtained as follows;

$$\text{Sample size (n)} = \frac{306508}{1+306508(0.07)^2} = 203.95 = 204$$

The study adopted a sample size of two hundred and twenty (220). This sample size has not taken into consideration the increase in the number of households between 2006 and present but this is not a problem as the figure is large enough to accommodate whatever increment there might have been. This assertion is based on a statement by Israel (2013) that one of the factors that determine the sample size is the method of analysis to be applied on the data. He opined that if descriptive statistics (e.g. mean and frequencies) are to be used, then nearly any sample size will suffice. But a good sample size of 200-500 is needed for multiple regressions, analysis of co-variance, or log-linear analysis, which might be performed for more rigorous state impact evaluations. According to Israel (2013), the sample size should be appropriate for the analysis that is planned.

3.7

Measurement of CO₂ Concentrations

3.7.1 Collection of Samples

The measurement involved collection and analysis of air samples to determine the CO₂ concentrations due to fuel consumption for the various activities from selected households in each of the clusters of the study. This was done to determine the extent to which CO₂ concentrations within the buildings and environs agree with recommended limit of 700ppm above outdoor concentration according to ASHRAE standard 62.1-2010 (HVAC Assessment Handbook, 2013). The activities from which CO₂ samples were collected are as follows:

- i. Power generation with petrol generators
- ii. Cooking with gas cookers
- iii. Cooking with kerosene stoves and
- iv. Cooking with fuel wood

Samples were collected from six households for each of the above mentioned activities in each of the clusters as was done by Stanley (2011). For power generation with petrol generators, samples were collected at the point of use (outside and very close to the generator) and inside the building mostly in the living room. Three readings were taken for each of the locations and the average was then calculated. These were done before and during the operation of the generators. 288 measurements (i.e. before and during the process outdoors and indoors in the living room) were recorded for determination of CO₂ concentration in houses as a result of the use of petrol to power generators.

For the cooking activities using LPG, kerosene and fuel wood, samples were collected from three locations in each of the surveyed houses. These were at the point of use of the equipment (usually in the kitchen for LPG and kerosene and sometimes outdoors in houses using fuel wood), in the living room and just outside the building. The measurements were taken before and during the operation of the equipment except outside the building in which case it was taken only once before the commencement of the process. Three readings were taken each time and their computed averages were used for the analyses. 360 readings were computed and recorded for each of the three activities of cooking with LPG, kerosene and fuel wood. The choice of the households was determined largely by their willingness to grant access.

Samples of CO₂ were also collected from nine locations within each cluster and averaged to determine its concentration. The justification for this is that since buildings do not exist in isolation from their environments, it will be in order to determine how they interfere with other factors to affect the environment and how these effects can be addressed at community level. This is also the understanding expressed by Cam (2012).

3.7.2 Instrument for CO₂ Measurement

The instrument that was used for measuring the concentration of CO₂ in the air is the Lutron CO₂/Humidity/Temperature Data Recorder. The instrument measures simultaneously the CO₂ concentration, temperature and the relative humidity of the air. This portable equipment for monitoring the quality of the environment has the capability for saving the recorded data into an SD memory card which can later be downloaded to Excel worksheet for analysis.

The accuracy of the instrument is ± 40 ppm when the concentration of CO₂ measured is not in excess of 1000 ppm. The accuracy is 5% of the reading when the reading is greater than 1000 ppm but less than or equal to 3000 ppm. Plate I in Appendix 5 shows the data recorder and the CO₂ sensor used in this study.

3.8 Analysis of Data

GHG emissions inventory was developed for the baseline year (2015) and the data for this was then projected for the forecast years (2020, 2035 and 2050) as was suggested in De Villiers and Matibe (2000). The inventory for the forecast years considered both the business as usual and the mitigation or policy scenarios. The data generated are presented in tables as weights of CO₂ equivalent (kgCO_{2e}) of GHGs emitted per year. The data generated include the following:

- a. Characteristics of the buildings including the building type, number of occupants, size of the buildings, whether the building is owned or leased.
- b. Energy consumption and emission data for the buildings. Energy consumption (in kWh) by the appliances is obtained from the product of the power rating of each appliance and the average daily duration of operation of the appliance. However for appliances that are only used occasionally for about half hour or less and their exact durations of usage could not be determined easily, 0.1 is adopted as the daily hours of use as was suggested by Alaskan alternative energy products and information (2008). These were then converted to annual energy consumption by multiplying with average annual duration of use. The power ratings of common household

appliances are presented in appendix 2 while appendix 4 presents the emission factors used for the computations. The factor in kg/kwh for CO₂ is 0.486277966 (Ecometrica, 2011). Only the emissions of CO₂ have been estimated as it has already been established in the literature that it accounts for over 98% of residential energy use emissions. Baseline emissions were calculated and then projected into the future for both business as usual (BAU) scenario and alternative policy or mitigation scenario.

Both descriptive (i and ii) and inferential (iii and iv) statistics were used in the analysis of data. The following specific tools were employed in analyzing the generated data;

- i. Measure of central tendency by the calculation of arithmetic means of various data sets using the relationship given in Stroud and Booth (2007) as follows.

$$\bar{X} = \frac{\sum f\chi}{\sum f} \text{-----} 3.2$$

Where \bar{X} is the mean, f is the frequency and χ represents the observations

- ii. Dispersions of values around the central value by calculation of standard deviations from the following relationship.

$$\sigma = \sqrt{\frac{\sum (X - \bar{X})^2}{N}} \text{-----} 3.3$$

Where σ is the standard deviation, $X - \bar{X}$ is deviation from the mean and N is the number of data sets.

- iii. Correlation and Regression statistics using Microsoft Excel. Correlation analysis was done to determine the nature of relationship that exists between some

parameters of the study and regression was used to analyze the strength of the relationships. A model for predicting fuel consumption by generators was developed and another for estimating energy consumption by A.Cs.

- iv. Single factor analysis of variance (ANOVA) of the emissions from the different scenarios over the years to determine if any statistically significant differences exist between them. The ANOVA is used to either reject the null hypothesis and accept the alternative hypothesis or refuse to reject the null hypothesis. The statistical criteria are if $P \leq \alpha$ (at 95% confidence level), the null hypothesis (H_0) will be rejected and the alternative (H_A) accepted and if $P > \alpha$ (at 95% confidence interval), the study will not be able to reject H_0 because no enough evidence is available to suggest that it is false (Martz, 2013).

CHAPTER FOUR

4.0 PRESENTATION AND ANALYSIS OF DATA

4.1 Characteristics of the Households

Two hundred and six (206) of the two hundred and twenty (220) questionnaires administered were validly completed and returned representing a response rate of 93.64%. Basic information about the studied households was collected. This includes a description of the type of household, the size of the building, total number of full-time occupants and the ownership status of the house. The data generated from this section of the questionnaire is presented in Table 4.1.

Table 4.1 shows that the predominant type of households studied are those on a separate yard (33.98%) and flats in blocks of flats (28.16%). Other types of houses are semi-detached house (16.02%) and rooms/let in houses (15.53%). Table 4.1 also show that 36 (17.48%), 44 (21.36%), 28 (13.59%) and 9 (4.37%) of the surveyed houses has an area not greater than 70m², between 71 – 100m², 101 – 200m² and greater than 200m² respectively. This gives the average area of the surveyed houses to be 85m².

Table 4.1: Characteristics of the Houses

S/N	Variables	Options	Frequency	Percentage (%)
1	House Type	House on a separate yard	70	33.98
		Flat in a block of flats	58	28.16
		Rooms/let in house	32	15.53
		Traditional/hut structure	12	5.83
		Semi-detached house	33	16.02
		Improvised dwelling	01	0.49
		Total	206	100
2	Size of the house (m ²)	Less than 70	36	17.48
		71 – 100	44	21.36
		101 – 200	28	13.59
		Greater than 200	09	4.37
		Declined response	89	43.20
3	Number of occupants	1 – 3	51	24.76
		4 – 7	82	39.81
		8 – 10	32	15.53
		Above 10	32	15.53
		Declined response	09	4.37
4	Tenancy	Owned	113	55
		Rented	87	42
		Declined response	06	03

It can be seen from Table 4.1 also that 24.76% of the studied households has 1 – 3 full time occupants, 39.81% has 4 – 7 occupants, while 15.53% of the houses has 8 – 10 and above 10 occupants each. This put the average number of occupants of the surveyed houses at six. This shows a slight increase over the 2006 National Population and Housing Census figure that put the average size of households in Kaduna at five. While 55% of the surveyed households stay in owned houses, 42% live in rented houses and 3% declined responding to this question. This reflects a house ownership of above average amongst the sampled households and by implication an indication of housing ownership needs in the city.

4.2

Energy Consumption Data of the Buildings

4.2.1 Sources of Energy for Household End Uses

Table 4.2 presents the various household energy consumption activities and their sources. For most of the listed household activities, grid electricity and petrol powered generators respectively are the main sources of energy with the exceptions to this trend being cooking and water heating.

Kerosene is the fuel used mostly (81.07%) for cooking in the houses that responded followed by wood (77.18%) and LPG (66.02%). The high usage of kerosene and wood might not be unconnected with availability and cost and preconceived fear of exploding LPG cylinders and fire outbreaks. For water heating, grid electricity is the energy source with the highest frequency (60.68%), followed by kerosene (34.95%) and firewood (25.24%). Despite the obvious environmental advantages offered by solar energy and the abundance of solar radiation in Nigeria, the results show that few households use this energy source for their needs (9.71% for lighting and 1.94% for powering entertainment equipment).

Table 4.2: Data on Energy Consumption in Buildings

S/N	Household Uses	Sources of Energy	Frequency	Percentage
1	Lighting	Grid Electricity	172	83.50
		Kerosene	18	8.74
		Petrol Powered Generator	111	53.88
		Diesel Powered Generator	06	2.91
		Solar PV Cells	20	9.71
		Declined Response	12	5.83
2	Cooking	Grid Electricity	60	29.13
		Kerosene	167	81.07
		Charcoal	43	20.87
		Gas	136	66.02
		Firewood	159	77.18
		Sawdust	10	4.85
3	Water Heating	Declined Response	8	3.88
		Grid Electricity	125	60.68
		Kerosene	72	34.95
		Charcoal	27	13.11
		Gas	29	14.08
		Firewood	52	25.24
4	Entertainment	Sawdust	5	2.43
		Declined Response	37	17.96
		Grid Electricity	146	70.87
		Petrol Powered Generator	59	28.64
		Diesel Powered Generator	6	2.91
		Solar PV Cells	4	1.94
5	Grinding	Declined Response	51	24.76
		Grid Electricity	106	51.46
		Petrol Powered Generator	44	21.36
		Diesel Powered Generator	2	0.97
6	Washing	Declined Response	77	37.38
		Grid Electricity	76	36.89
		Petrol Powered Generator	18	8.74
		Diesel Powered Generator	2	0.97
		Declined Response	124	60.19

The data also show that the households use different energy mixes for the various tasks depending, probably on convenience, availability and suitability. This explains why the percentages for each of the various tasks will not add up to 100. It can also be observed that a reasonable number of households declined responding to some of the questions.

4.2.2 Energy use for Ventilation

Information about the number and type of fans used by the houses as well as their usage data is presented in Table 4.3.

Table 4.3: Ventilation Energy Consumption Data

S/N	Variables	Options	Frequency	Percentage
1	Number of fans	1	11	5.34
		2	35	16.99
		3	42	20.39
		4	30	14.56
		5	24	11.65
		>5	57	27.67
		Declined	7	3.40
	Total	206	100.00	
2	Fan type	Ceiling	662	76.80
		Standing	183	21.23
		Wall	17	1.97
		Total	862	100.00
3	Average daily duration of use (hours)	1 – 3	28	14.07
		4 – 6	91	45.73
		7 – 9	40	20.10
		10 and above	40	20.10
4	Days used in a week	1 – 3	32	16.08
		4	25	12.56
		5	40	20.10
		>5	102	51.26
5	Houses with other fan types	Solar	16	7.77

Table 4.3 shows that 91.26% of the surveyed houses have at least two fans of which 76.80% are ceiling mounted, 21.23% are standing and 1.97% is fixed to the walls. 14.07% of the houses indicated that they operate the fans for not more than 3 hours, 45.73% and 20.10% operate their fans for between 4-6 hours and 7-9 hours daily respectively. Another 20.10% operates their fans for an average of 10 hours daily. 16.08% of the houses operate

the fans for not more than 3 days weekly while the remaining 83.92% operates theirs for at least 4 days weekly. 16 (7.77%) of the surveyed houses also use solar energy powered fans. The fans are used an average of 5 days in a week for an average of 4.8 hours in a day. 878 fans were counted from the houses surveyed.

4.2.3 Energy use for Cooling

This section presents information about the use of air conditioners (A.C) to achieve comfortable indoor temperatures by the households.

Table 4.4: Cooling Energy Consumption Data

S/N	Variables of Study	Options	Responses	Percentage
1	Possession of A.C	Yes	90	43.69
		No	111	53.88
2	Number of A.Cs	1	27	30.00
		2	27	30.00
		3	16	17.77
		4	20	22.22
3	Average number of days used in a week	1 – 2	11	12.22
		3	19	21.11
		4	18	20.00
		5 – 7	42	46.67
4	Average daily use duration (hours)	1 – 2	7	7.77
		3 – 4	48	53.33
		5 – 6	24	26.67
		7 and above	11	12.22

Table 4.4 contains data on the number of A.Cs owned by households and their frequency of operation. As presented in Table 4.4, 43.69% of the studied households have air conditioners, 53.88% does not have and 2.43% declined responding to the question on this aspect of the study. 30% of the houses each have 1 and 2 air conditioners installed while 17.77% and 22.22% has 3 and 4 respectively. 209 A.Cs were enumerated from the

surveyed households. The air conditioners are operated on an average of 4 days in a week for an average of 4 hours per day.

4.2.4 Food Preparation and Cooking

Preparation, preservation as well as cooking of food employs a variety of equipment in buildings and the extent of possession of the commonest ones by the surveyed households are presented in Figure 4.1.

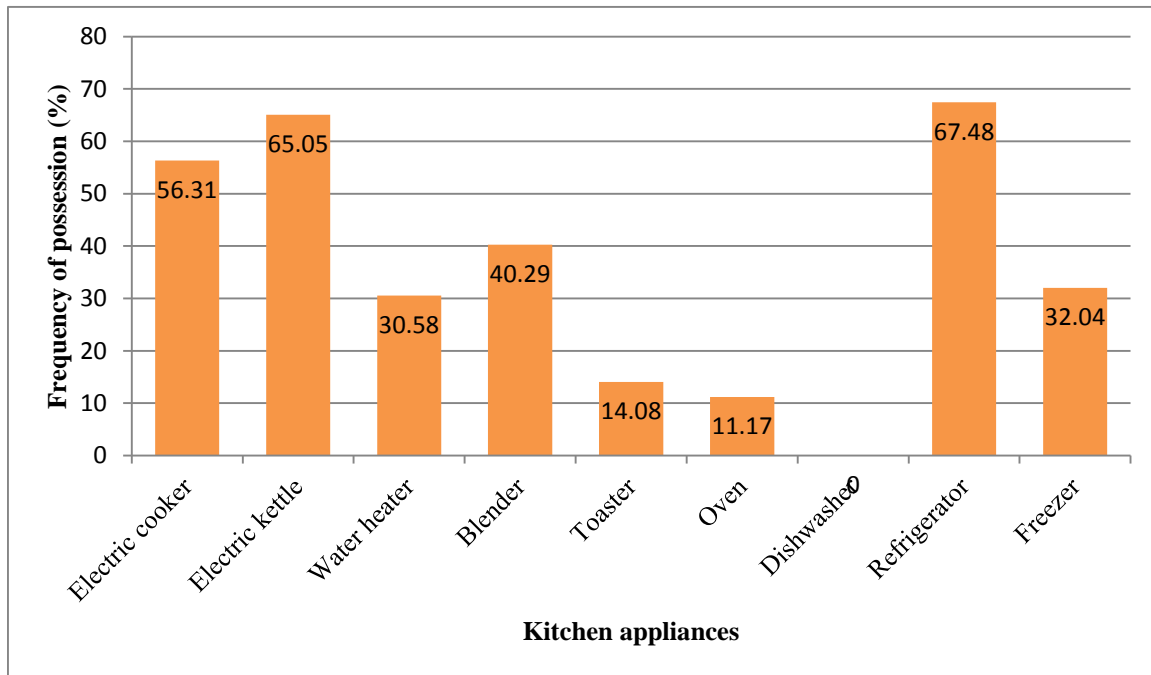


Figure 4.1: Households' Possession of Food Preparation and Cooking Appliances

Figure 4.1 shows the most possessed kitchen appliances by surveyed households to be refrigerator (67.48%), electric kettle (65.05%), electric cooker (56.31%), blender (40.29%) and freezer (32.04%). The frequencies of use of these appliances are shown in appendix 3.

4.2.5 Energy for Lighting

Table 4.5a shows that the commonest type of light bulbs used by households is the fluorescent bulbs (641 units used in 94 households), followed by tungsten filament bulbs (617 units in 91 houses) and compact fluorescent bulbs (474 units installed in 62 of the studied houses). This has revealed that though many households use the energy efficient light fittings, the use of inefficient filament bulbs is still on the high side (44.17% of total of 206 households studied). Ignorance could be the reason for the continued use of filament lamps by these households despite the availability of the more efficient CFLs and LEDs.

Table 4.5a: Data on Lighting in Studied Households

Types of light bulbs	No. of Houses	Total no. of bulbs	Average daily hours of use
Tungsten filament bulbs	91	617	9
Fluorescent tubes	94	641	8
Compact fluorescent bulbs	62	474	8
Halogen lamps	19	67	9
Light emitting diodes	5	24	5

Table 4.5b: Other Lighting Data

S/N	Variables	Options	Frequency	Percentage
1	Practice of task lighting	Yes	64	31.07
		No	104	50.49
2	Motivation for task lighting	Money saving	20	31.25
		Energy saving	22	34.38
		Sustainability	4	6.25
		All the above	18	28.13
3	Switching off lights not in use	Always	86	41.75
		More often than not	36	17.48
		Rarely	19	9.22
		Never	1	0.49

Table 4.5b shows that only 64 (31.07%) of the surveyed houses practice task lighting as against general overhead lighting while 104 (50.49%) does not. 38 households (18.44%) did not respond to the question on this. This leaves a lot to be desired as regards energy saving and emissions reduction from this practice. The motivations for task lighting by the houses that responded are money saving (20), energy saving (22), sustainability (4) and the combination of all the listed motivations (18). Lights not in use are always switched off in 86 of the houses, switched off more often than not in 36 of the houses and rarely switched off in 19 houses while in one house, the lights are permanently on. This implies that a lot of energy saving as well as emission reductions can be achieved through the advocacy of the practice of switching lights off when not in use.

4.2.6 Use of Energy for Entertainment

Different households employ varying means of relaxation and amusement at home. Table 4.6 presents the commonest equipment used for achieving this by the surveyed houses and their duration of operation of the equipment.

Table 4.6: Possession of Entertainment Equipment and Daily Energy Use Data

S/N	Appliances	Frequency (no)	Percentage	Average use Duration
1	Television	192	93.20	8
2	Digital Video Disc	153	74.27	4
3	Hi fi system	23	11.17	3
4	Cassette recorder	25	12.14	2
5	Stereo system	46	22.33	4
6	Satellite decoder	152	73.79	7

From Table 4.6, the entertainment equipment most possessed by the surveyed households is television (192 houses), digital video disc (153 houses) and satellite decoder (152 houses). Their mean daily duration of operation are as presented in the table.

4.2.7 Energy Use for Laundry

Table 4.7: Weekly laundry energy use data

S/N	Appliances	Frequency (no)	Percentage	Ave. usage	Ave. duration (hrs)
1	Washing machine	42	20.39	2	1
2	Clothes dryer	19	9.22	2	1
3	Pressing iron	169	82.04	3	1.5

Table 4.7 shows that 169 (82.04%) of the studied households possess pressing iron which they use an average of 1½ hours for 3 days in a week. Other laundry equipment are washing machines possessed by 42 (20.39%) of the houses and clothes dryer owned by 19 (9.22%) of the households. The average durations of use per cycle of use are as presented in Table 4.7.

4.2.8 Use of Energy for Sanitation and Hygiene

The data obtained from households about the equipment they use for maintaining clean and healthy bodies and the frequency of use of the equipment are as shown in Table 4.8.

Table 4.8: Households' Weekly Energy use Data for Sanitation and Hygiene

S/N	Appliances	Frequency (no)	Percentage	Ave. usage	Ave. duration (mins)
1	Water heater	43	20.87	6	45
2	Hair shaver	43	20.87	2	30
3	Hair dryer	26	12.62	1	20
4	Vacuum cleaner	15	7.28	1	45

Table 4.8 shows the frequency of possession of sanitation and hygiene related household electrical equipment with the average number of days used weekly and duration of use per day.

4.2.9 Energy Use by other Household Appliances

Table 4.9: Weekly Energy Use Data from other Household Appliances

S/N	Appliances	Frequency (no)	Percentage	Ave. usage	Ave. duration (mins)
1	Desktop	37	17.96	3	180
2	Laptop	128	62.14	5	180
3	Printer	35	16.99	1	20
4	Scanner	14	6.80	1	10
5	Lawn mower	3	1.46	1	20
6	Water pump	44	21.36	4	120

Table 4.9 presents other appliances used at home which has not been captured under any of the previous sections. Of the listed appliances in Table 4.9, laptop computer (128) is the most possessed by the households surveyed. This is followed by water pump (44), desktop computer (37), printer (35), scanner (14) and lawn mower (3) respectively.

4.3

Onsite Energy Generation and Consumption

4.3.1 Electricity Generation on Site

This section obtained information from the surveyed houses about the means of energy generation on site, the rated capacity of the generators, number of days the generators are operated in a week, average duration of operation (hours) and the types of fuel used. Table 4.10 presents the results.

Table 4.10: On-site Energy Generation and Consumption

S/N	Variables	Options	Frequency	Percentage
1	Onsite Sources of Electricity	Petrol Generator	155	75.24
		Diesel Generator	6	2.91
		Solar PV Cells	3	1.46
		Windmill	0	0.00
2	Rating of Generator (KVA)	0.65	26	16.15
		0.70	24	14.91
		2.00	41	25.47
		2.50	51	31.68
		5.00	19	11.80
3	Operation of Generator/week	≥ four days	55	34.16
		Thrice	64	39.75
		Twice	32	19.88
		Once	10	6.21
4	Average hours of operation	< 1 hour	3	1.86
		1-2 hours	29	18.01
		2-3 hours	67	41.61
		3-5 hours	40	24.84
		> 5 hours	22	13.66
5	Fuel used/operation (litres)	< 2	48	29.81
		2-5	74	45.96
		5-10	33	20.50
		> 10	6	3.73

The study revealed that 155 (75.24%) of the surveyed households possess petrol powered generators, 6 (2.91%) has diesel powered generators and only 3 (1.46%) have solar

photovoltaic (PV) cells installed for electricity generation. None of the houses have a windmill installed. This means that despite the advantages of these renewable energy technologies and the energy crises in Nigeria, households are not making good use of these benefits. 31% of the generators are rated 0.65-0.7KVA, 25.47% are rated at 2.00KVA, 31.68% are rated at 2.5KVA and 12% are rated at 5.00KVA. The generators are operated on an average of 4 days a week for an average of 4 hours. Estimated average fuel consumption for each day of operation is 5 litres.

4.3.2 Quantities of Cooking Fuels Consumed by Households

The data on fuel consumption for the various cooking activities indulged in by the households are as presented in Table 4.11.

Table 4.11: Types of fossil fuels and biomass used for cooking by surveyed houses

S/N	Fuel type	Frequency	Percentage
1	Kerosene	167	81
2	LPG	136	66
3	Wood	159	77

Table 4.11 shows kerosene to be the predominant fuel for cooking by the surveyed houses. Fuel wood comes next and then cooking gas (LPG). Table 4.11 also indicates that most of the surveyed houses use more than one type of fuel for cooking. Lack of popularity of LPG as a cooking fuel could be attributed to the preconceived notion about its safety and cost.

Table 4.12: Quantity of kerosene consumed by households monthly

Quantity (Litres)	Frequency	Percentage
1 – 3	25	12
4	74	36
5 – 7	49	24
8	25	12
9 – 11	25	12
12	8	4

Table 4.12 shows that 36% of the houses use 4 litres of kerosene for cooking monthly, 24% uses 5 to 7 litres monthly while 12% each uses 1 to 3 litres, 8 litres and 9 to 11 litres respectively. 4% of the houses indicated that they use 12 litres for cooking monthly. The average monthly consumption of kerosene from the houses that responded to the question on this is 5.76 litres. Based on the average household size of 6, this gives a per capita monthly consumption of 0.96 litres while the daily consumption/capita is 0.032 litres.

Table 4.13: Quantity of LPG consumed by households

Capacity of cylinder (kg)	Frequency	Percentage	Weeks of use
3	21	10	2
6	45	22	3.5
9	10	5	8
12.5	122	59	5
47.5	10	5	16

The commonest size of gas cylinder in use by the houses is the 12.5kg (59%), followed by the 6kg cylinder (22%) and 3kg (10%) as shown in Table 4.13. The average LPG consumption is estimated to be 12.5kg by an average household in 5 weeks. Based on an average household size of 6 people, the daily per capita LPG consumption is computed to be 0.06kg.

Table 4.14: Summary of quantities of biomass and fossil fuels consumed by households

Fuel type	Density (kg/m ³)	Consumption/capita (kg)		Household consumption (kg)	
		Daily	Annually	Daily	Annually
Petrol	740	N/A	N/A	3.7	770
Kerosene	810	0.026	9.49	0.156	56.94
LPG	N/A	0.06	21.9	0.36	131.4
Wood	N/A	0.776	283.24	4.66	1701

Fuel wood is by far the fuel consumed the most by the households as is presented in Table 4.14. An average household consumes 1.7 metric tonnes annually. This is followed by petrol for powering of portable generators to supplement grid electricity. Average household consumption of petrol/ annum is 770kg. Average household consumption of LPG/annum is 131.4kg while that of kerosene is 56.94kg. This is despite the fact that more households use kerosene than LPG. A possible explanation for this could be that while households that use LPG rely on it most of the times, many of those who use kerosene often combines it with other fuel types such as wood charcoal and sawdust.

4.4 Energy Use Patterns and Behavioural Adaptations

4.4.1 Energy Use Preference

Households were requested to indicate their level of preference of identified cooking methods on a scale of 1 – 5 where 1 is the most preferred option and 5 is the least preferred.

Table 4.15 presents the responses.

Table 4.15: Households Preference of Energy Type for Cooking

S/N	Energy Option	Preference / Frequency (<i>f</i>)					$\sum f$	Mean	Rank
		1	2	3	4	5			
1	Electric cooker	68	33	25	8	20	154	2.21	2
2	Gas cooker	73	39	15	13	20	160	2.18	1
3	Kerosene stove	42	33	56	21	14	166	2.59	3
4	Fire wood	11	18	27	40	21	117	3.36	4
5	Saw dust stove	4	6	6	22	30	68	4.00	6
6	Charcoal stove	2	12	10	26	25	75	3.80	5
7	Dung	0	2	2	5	26	35	4.57	7

1 is the most preferred and 5 is the least preferred.

The preference of the surveyed households for the listed energy types for cooking indicate that cooking with gas is the most preferred. This is followed by the use of electricity, kerosene, wood, charcoal, sawdust and dung respectively (Table 4.15). The ranking of gas as the most preferred cooking fuel is an indication of the high level of awareness of the households about the advantages of cooking with gas and this implies that a lot of reduction in GHG emissions through cooking with electricity and biomass (wood, sawdust and dung) can be achieved through some advocacy and support to households by government to acquire gas cylinders and cookers and also some subsidy on the cost of gas.

Table 4.16: Level of Observance of Energy Efficiency Measures

S/N	Energy efficient measures	Level of observance					$\sum f$	Mean	SD
		1	2	3	4	5			
1	Closing doors and windows when the AC is on	98	22	12	16	27	175	2.15	1.65
2	Cleaning AC's air filters at least once a month	38	48	37	18	30	171	2.73	1.44
3	Using shades to prevent overheating by sun	52	45	23	23	27	170	2.58	1.48
4	Changing inefficient AC systems	40	37	42	23	29	171	2.79	1.43
5	Use of fans to circulate cooled air	72	45	29	22	17	185	2.28	1.59
6	Using ceiling fans to cool off	53	49	37	25	19	183	2.50	1.50
7	Replacing incandescent bulbs	53	34	50	27	20	184	2.60	1.47
8	Using timers to turn lights on and off	33	23	51	28	46	181	3.17	1.42
9	Use microwaves and toaster ovens	26	36	46	31	35	174	3.07	1.47
10	Replacing old refrigerators	27	44	44	32	29	176	2.95	1.41
11	Air drying clothes as against machine drying	54	35	26	19	36	170	2.69	1.45
12	Keeping the oven door closed while cooking	57	33	21	33	29	173	2.68	1.45
13	Matching the pot size to the burner on the stove	53	34	38	29	28	182	2.70	1.45
14	Using tight-fitting covers on pots and pans	57	52	35	19	22	185	2.44	1.52
15	Washing with cold water instead of hot water	64	38	41	17	21	181	2.41	1.53
16	Use of solar water heater for energy saving	27	29	33	32	44	165	2.68	1.45
17	Full loading of washing machine	29	37	26	34	46	172	3.18	1.42
18	Unplugging battery chargers when not in use	88	33	24	16	27	188	2.26	1.60

1-Very high 2 - High 3 - Low 4- Very low 5 - Does not observe

Table 4.16 shows that the level of observance of the listed energy efficiency measures is low with the exception of five measures whose observances are high. The exceptions are closing doors and windows when the AC is on, use of fans to circulate cooled air, using tight-fitting covers on pots and pans, washing with cold water instead of hot water and

unplugging battery chargers when not in use. These practices with low level of observance present yet another set of opportunities for mitigating GHG emissions. Proper enlightenment of households by government agencies and non-governmental organizations (NGOs) concerned with the conservation of environment can contribute to the reduction of GHGs associated with these inefficient practices.

4.4.2 Behavioural Adaptations

Behavioural changes that can bring about significant reduction in energy consumption and consequently GHG emissions by households were identified from literature and households were asked to rank their level of willingness to adopt these energy efficient measures on a scale of 1 – 5 where 1 indicate a very high level of willingness by the house and 5 indicates lack of preparedness to adopt such measures. Their responses are as presented in Table 4.17.

Table 4.17: Willingness of Households to Accept Behavioural Changes

S/N	Suggested behavioural changes	Willingness to accept					Σf	Mean	SD
		1	2	3	4	5			
1	Turn off lights and appliances when not in use	145	14	11	12	8	190	1.56	2.01
2	Task lighting instead of overhead lighting	73	42	31	24	17	187	2.30	1.58
3	Use daylight for reading, working and living	100	38	33	11	5	187	1.84	1.83
4	Use of lighter colours on walls and ceiling	83	52	23	19	11	188	2.06	1.64
5	Replace all incandescent bulbs	107	36	23	15	10	191	1.87	1.81
6	Keep lights and lighting fixtures clean	93	48	27	16	4	188	1.88	1.80
7	Reduce heat gain by planting trees	90	47	25	18	11	191	2.02	1.72
8	Cool food before it goes into the refrigerator	91	47	28	12	9	187	1.78	1.86
9	Clean the reflectors underneath the burners	76	50	39	17	8	190	2.04	1.71
10	Fill the freezer by using water-filled bottles	69	44	33	23	16	185	2.31	1.63
11	Replacing appliances over ten years old	61	58	33	22	11	185	2.26	1.60
12	Improve lighting controls by using sensors	50	47	38	28	26	189	2.65	1.46
13	Clean cooling coils on a regular basis	59	56	39	18	17	189	2.07	1.69
14	Installation of renewable energy technologies	72	50	34	18	10	184	2.21	1.62
15	Solar water heating instead of electricity	59	39	40	19	24	181	2.50	1.50
16	Switching to cool roofs	82	29	31	26	20	188	2.32	1.57

1 - very high willingness, 2 - high willingness, 3 - low willingness,
4 - very low willingness and 5 - not willing.

It can be observed from Table 4.17 that the surveyed houses indicated high level of willingness to adopt all but two of the suggested measures aimed at improving energy use efficiency in buildings and consequently lower emission of GHGs. The measures the households are not too enthusiastic to embrace are improvement of lighting controls by

using sensors and solar water heating instead of the use of electricity. The relatively small values of the standard deviations are an indication of the closeness of the willingness of households to adopt the suggested measures to the mean.

4.5 Estimation of Baseline Carbon Dioxide Emissions

The baseline year adopted for the development of the mitigation strategy in this study is the year 2015. The energy use data for the various household activities and appliances were collected in January, 2015 from the households that participated in the study. The data are as presented previously in sections 4.1 to 4.4 of this chapter and some of this data is presented in Appendix 3. The baseline emissions are estimated for the direct emissions as well as for the indirect emissions.

4.5.1 Direct CO₂ Emissions

The on-site emission of GHGs from the studied households can be attributed to two activities; these are on-site energy generation through the use of generators and food preparation. The generators are powered mainly by petrol and in some few cases diesel. The predominant fuels for cooking are kerosene, LPG and wood. The emission factors used (refer to Table 4.18) are those given in UNEP SBCI (2009).

The populations of the households using the different types of fossil fuels are as previously presented in Table 4.2 while the quantities of the various fuels consumed by the households

are as estimated in Tables 4.10 to 4.14. The quantities of CO₂ emitted from the activities that use these fuels are presented in Table 4.18.

Table 4.18: Direct Baseline Emissions of CO₂ Annually

Activity	Fuel type	NoH	AAHC (kg)	TC (tonnes)	EF (kg/tonne)	AAHE (tonnes)	TE (tonnes)
Power gen.	Petrol	155	770	119.35	3186.30	2.45	379.75
Cooking	Kerosene	155	56.94	8.83	3149.22	0.18	27.90
Cooking	LPG	105	131.40	13.8	2984.63	0.39	40.95
Cooking	Biomass	141	1701	239.84	1747.20	2.97	418.77
Total						5.66	867.37

NoH – Number of houses

AAHC – Average annual household consumption (kg)

TC – Total consumption by the surveyed houses annually (tonnes)

EF – Emission factor (kg/tonne)

AAHE – Average annual household emission (tonnes)

TE – Total emission (tonnes) per annum from the surveyed houses

Power gen. – Power generation with generators on site

The greatest direct emission of CO₂ from the surveyed houses (418.77 metric tonnes) is attributable to the use of fuel wood and its derivatives i.e. charcoal and sawdust for cooking despite having the lowest emission factor. The reason for this is because of the large quantities used. This is followed by petrol, LPG and kerosene respectively. Kerosene has a higher emission factor than LPG implying that a greater amount of CO₂ will be emitted from the use of kerosene compared to consumption of an equal quantity of LPG but because larger quantities of LPG are used by the surveyed houses, it also generates more of CO₂.

4.5.2 Regression Analysis for Determinants of Petrol Consumption

It is deemed necessary to conduct a regression analysis for the factors affecting petrol consumption by generators because it is the second largest emitter of CO₂ from households and a number of factors have been identified to be responsible for consumption and hence the emissions. The regression analysis is aimed at producing a model that can be used to predict how the various parameters will individually affect fuel consumption when others are kept constant. Fuel consumption (C) is the dependent or Y – variable while the independent or the X – variables are the rating of the generator (R), number of days the generator is operated per week (D) and average hours of operation daily (H). A precursor activity to this is correlation analysis which showed a weak positive linear relationship between fuel consumption and the independent variables.

Table 4.19: Regression Analysis for Factors Affecting Petrol Consumption by Generators

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.621662
R Square	0.386464
Adjusted R ²	0.374274
Standard Error	1.954578
Observations	155

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	0.529051	0.482963485	1.095427	0.275074	-0.4251874	1.483290064
Rating	0.639303	0.120889011	5.288348	4.26E-07	0.400450813	0.878155569
Days/week	-0.09386	0.077620611	-1.20926	0.228453	-0.24722619	0.05949925
Hours/day	0.875702	0.119371704	7.335923	1.26E-11	0.639847121	1.111556088

Table 4.19 shows the results of the multiple regression analysis conducted on the factors. Only 37% of changes in the quantity of fuel consumed by the generators are caused by a combination of the independent variables identified (from the coefficient of determination R^2). The generator rating and hours of operation per day have low P – values signifying that they are likely to be a significant addition to the regression model i.e. their effect on fuel consumption is significant. However the P – value for days of operation per weekly is higher than the common alpha level of 0.05, which indicates that it is not statistically significant and would not form part of the regression model.

Regression coefficients represent the mean change in the dependent variable (fuel consumption in this case) for one unit of change in the independent variable (R, D or H) while holding other independent variables in the model constant. This statistical control that regression provides is important because it isolates the role of one variable from all of the others in the model (Frost, 2013). The regression model is given in equation 4.1.

$$C = 0.5291 + 0.6393R + 0.8757H \text{ ----- 4.1}$$

4.5.3 Indirect CO₂ Emissions

The baseline emissions below have been estimated from the energy use data and the emission factors using Equation 2.1. This equation multiplies the electricity consumption by each appliance by the emission factor for the GHG to get the amount of the gas emitted per annum. The electricity consumption is the 71.5% generated from the thermal plants using fossil fuels. The emission factor used is obtained from Appendix 4. These are the indirect emissions (scope 2) resulting from electricity use. The results are as shown in

Table 4.20. Only the emissions of CO₂ are calculated as it accounts for over 98% of all household energy use induced emissions.

Table 4.20a: Baseline CO₂ Emissions from cooling, lighting and ventilation

S/N	Apps.	NoA	Rating (kW)	AADoO (h)	AAECpA (kWh)	AAEpA (kgCO ₂ /yr)	TECbSH (MWh)	TCEfSH (tCO ₂ /yr)
1	Fans	878	0.04	1248	35.69	17.35	31.34	15.24
2	A. C.	209	1	832	594.88	289.27	124.33	60.46
3	FI bulb	617	0.1	3285	234.88	114.21	144.92	70.47
4	Fluores	1115	0.03	2920	62.63	30.46	69.83	33.96
5	Halo.	67	0.1	3285	234.88	114.21	18.33	7.65
6	LEDs	24	0.02	1825	26.10	12.69	0.63	0.31
	Total						389.37	188.09

Apps. – Appliances

NoA – Number of appliances

A. C. – Air conditioner

FI bulb – Filament bulb

Fluores – Fluorescent bulb

Halo. – Halogen bulb

AADoO – Average annual duration of operation (hrs)

AAECpA – Average annual electricity consumption per appliance (kWh)

AAEpA – Average annual emission/appliance

TECbSH – Total electricity consumption by the surveyed houses due to the use of the app

TCEfSH – Total CO₂ emission from surveyed houses due to the use of the app

Table 4.20a shows that filament bulbs is the most energy consuming of all the equipment presented on this table despite the fact that fewer of them than the fluorescent bulbs and fans are installed. This is a pointer to their highly energy intensive and less efficient nature. The replacement of these with compact fluorescent lamps and light emitting diodes (LEDs)

presents a good opportunity for cutting down energy consumption and consequently emission of GHGs. 209 air conditioners installed in the surveyed houses produced a total annual emission of 60.46 tonnes of CO₂. This is obviously due to their higher power rating. It can also be observed that despite the higher energy intensity of the air conditioners, the sum of emissions from them is not as high as those from filament lamps. This is because apart from the inefficient nature of the filament lamps, they are more abundant and also used for longer periods.

From Table 4.20b the refrigerator (139), electric kettle (134) and cooker (116) are the kitchen appliances possessed most by the studied households. However in terms of emission of CO₂, the cooker emits by far the most (123.53tCO₂/yr) because of their greater power rating and numbers and relatively higher frequency of usage, followed by the kettle (39.96tCO₂/yr), refrigerator (16.65tCO₂/yr) and water heater (14.09tCO₂/yr) respectively. The emissions from the use of blenders (0.16 tCO₂/yr), toasters (0.29 tCO₂/yr) and microwave ovens (2.45tCO₂/yr) are respectively the lowest because households possess fewer of them and they are also used less frequently.

Table 4.20b: Baseline CO₂ Emissions from electrical kitchen appliances

S/N	Kitchen Appls	No. of apps.	Rating (kW)	AADoO (h)	AAECpA (kWh)	AAEpA (kgCO ₂ /yr)	TECbSH (MWh)	TCEfSH (tCO ₂ /yr)
1	Cooker	116	2	1095	1565.85	761.44	181.64	88.32
2	Kettle	134	2	306.6	438.44	213.21	58.75	28.57
3	Heater	63	1.5	306.6	328.83	159.90	20.71	10.07
4	Blender	83	0.3	13.52	2.90	1.41	0.24	0.11
5	Toaster	29	1.2	17.16	14.72	7.16	0.43	0.21
6	Microwave	23	1.2	182.5	156.59	76.15	3.60	1.75
7	Fridge	139	0.15	1642.5	176.16	85.66	24.49	11.90
8	Freezer	66	0.2	1642.5	234.88	114.21	15.50	7.54
	Total						305.36	148.49

No. of apps. – Number of appliances

AADoO – Average annual duration of operation (hrs)

AAECpA – Average annual electricity consumption per appliance (kWh)

AAEpA – Average annual emission per appliance

TECbSH – Total electricity consumption by the surveyed houses due to the use of the app

TCEfSH – Total CO₂ emission from surveyed houses due to the use of the appliances

Table 4.20c: Baseline CO₂ emissions from entertainment

S/	Entert.	No. of	Rating	AADoO	AAECpA	AAEpA	TECbSH	TCEfSH
N	Apps.	apps	(kW)	(h)	(kWh)	(kgCO ₂ /yr)	(MWh)	(tCO ₂ /yr)
1	TV set	192	0.2	2920	417.56	203.05	80.17	38.99
2	DVD	153	0.03	1460	31.32	15.23	4.79	2.33
3	Hifi	23	0.7	1095	548.05	266.50	12.61	6.13
4	C. R	25	0.24	730	125.27	60.92	3.13	1.52
5	Stereo	46	0.02	1460	20.88	10.15	0.96	0.46
6	Decoder	152	0.03	2555	54.80	26.65	8.33	4.05
Total							110.00	53.49

AADoO – Average annual duration of operation (hrs)

AAECpA – Average annual electricity consumption per appliance (kWh)

AAEpA – Average annual household emission

TECbSH – Total electricity consumption by the surveyed houses due to the use of the app

TCEfSH – Total CO₂ emission from surveyed houses due to the use of the appliance

Entert. – Entertainment

Table 4.20c shows that over 70% of emissions attributable to the operation of household entertainment appliances are from television sets. This is because almost all the houses surveyed have at least one and they are also among the most frequently used of all household appliances together with the satellite decoder. The emissions from other appliances in this category are as presented in Table 4.20c.

Table 4.20d: Baseline CO₂ emissions from household sanitation and body hygiene

S/N	Household Appliances	No. of appls.	Rating (kW)	AADoO (h)	AAECpA (kWh)	AAEpA (kgCO ₂ /yr)	TECbSH (MWh)	TCEfSH (tCO ₂ /yr)
1	W. machine	42	0.4	104	29.744	14.46	1.25	0.61
2	Clothes dryer	19	4	104	297.44	144.64	5.65	2.75
3	Pressing iron	169	1	234	167.31	81.36	28.28	13.75
4	Water heater	43	1.5	234	250.97	122.04	10.79	5.25
5	Hair shaver	43	0.015	52	0.56	0.27	0.02	0.01
6	Hair dryer	29	1	36.5	37.18	18.08	1.08	0.52
7	V. cleaner	15	0.5	39	13.94	6.78	0.21	0.10
	Total						47.28	23.00

AADoO – Average annual duration of operation (hrs)

AAECpA – Average annual electricity consumption per appliance (kWh)

AAEpA – Average annual emission per appliance

TECbSH – Total electricity consumption by the surveyed houses

TCEfSH – Total CO₂ emission from surveyed houses due to the use of the appliance

W. machine – Washing machine

V. cleaner – Vacuum cleaner

Table 4.20d presents the total emissions due to the use of household sanitation and body hygiene equipment. Pressing iron emits the greatest (13.75tCO₂/yr), followed by water heater (5.25tCO₂/yr), clothes dryer (2.75tCO₂/yr), washing machine (0.61tCO₂/yr) and hair dryer (0.52tCO₂/yr). The operation of the vacuum cleaner and hair shaver only emit 0.10tCO₂/yr and 0.014tCO₂/yr respectively.

Table 4.20e: Baseline emissions from the use of other household appliances

S/N	Appls	No. of apps.	Rating (kW)	AADoO (h)	AAECpA (kWh)	AAEpA (kgCO ₂ /yr)	TECbSH (MWh)	TCEfSH (tCO ₂ /yr)
1	Desktop	37	0.15	468	50.19	24.41	1.86	0.90
2	Laptop	128	0.045	780	25.10	12.21	3.21	1.56
3	Printer	35	0.1	36.5	2.61	1.27	0.09	0.04
4	Scanner	14	0.18	36.5	4.79	2.28	0.06	0.03
5	H ₂ O pump	44	1.5	416	446.16	216.96	19.63	9.55
	Total						24.85	12.08

AADoO – Average annual duration of operation (hrs)

AAECpA – Average annual electricity consumption per appliance (kWh)

AAEpA – Average annual emission per appliance

TECbSH – Total electricity consumption by the surveyed houses due to the use of the app

TCEfSH – Total CO₂ emission from the surveyed houses due to the use of the appliance

Table 4.20e presents the emissions from other household appliances which are not part of the previous grouping of appliances (tables 4.20a - 4.20d). Water pumps account for the greatest emission of 9.55tCO₂/yr obviously because of their higher power rating. This is followed by laptop (1.56tCO₂/yr) and desktop (0.90tCO₂/yr) computers respectively. Emissions attributable to these equipment are as presented in Table 4.20e.

4.5.4 Aggregation of Residential Indirect CO₂ Emissions by Energy use Category

Tables 4.20a – e shows the energy use and emissions from the various household activities. The household activities associated with the storage, preparation and cooking of food are responsible for the greatest emission of 148.49tCO₂/year from the surveyed houses. The

others are lighting from which 112.39tCO₂/year are emitted; cooling and ventilation emitting 75.70tCO₂/year; entertainment which emits 53.49tCO₂/year; sanitation and hygiene emitting 23.00tCO₂/year and other appliances which are accountable for the emission of 12.08tCO₂/year. Figures 4.2, 4.3 and 4.4 respectively summarize the electrical energy use intensity, the fraction generated from thermal plants (using fossil fuels) and emissions from the various household activities from the surveyed houses.

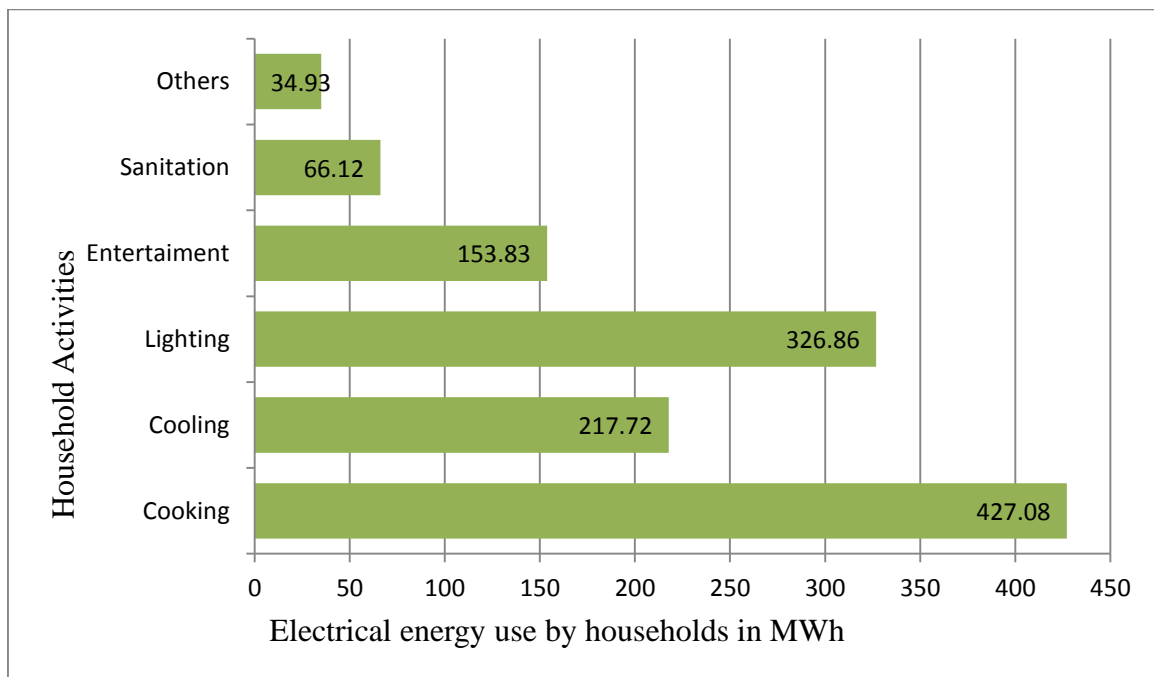


Figure 4.2: Electrical Energy Use by the Household Activities

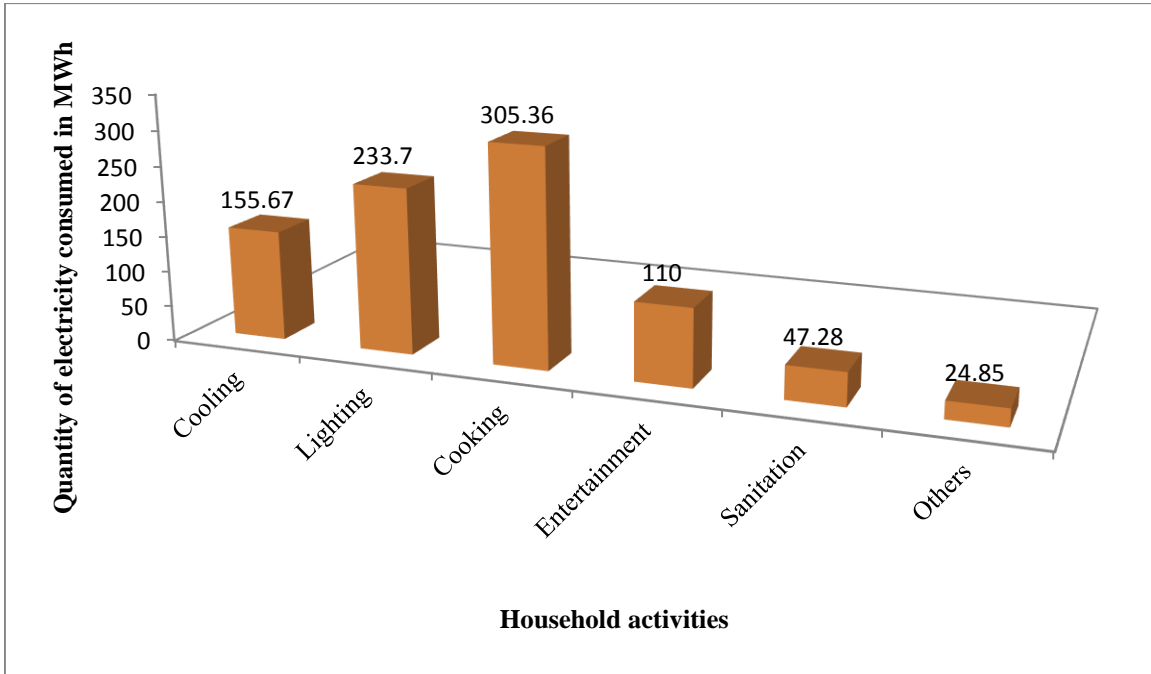


Figure 4.3: Fraction of Electricity from Thermal Plants

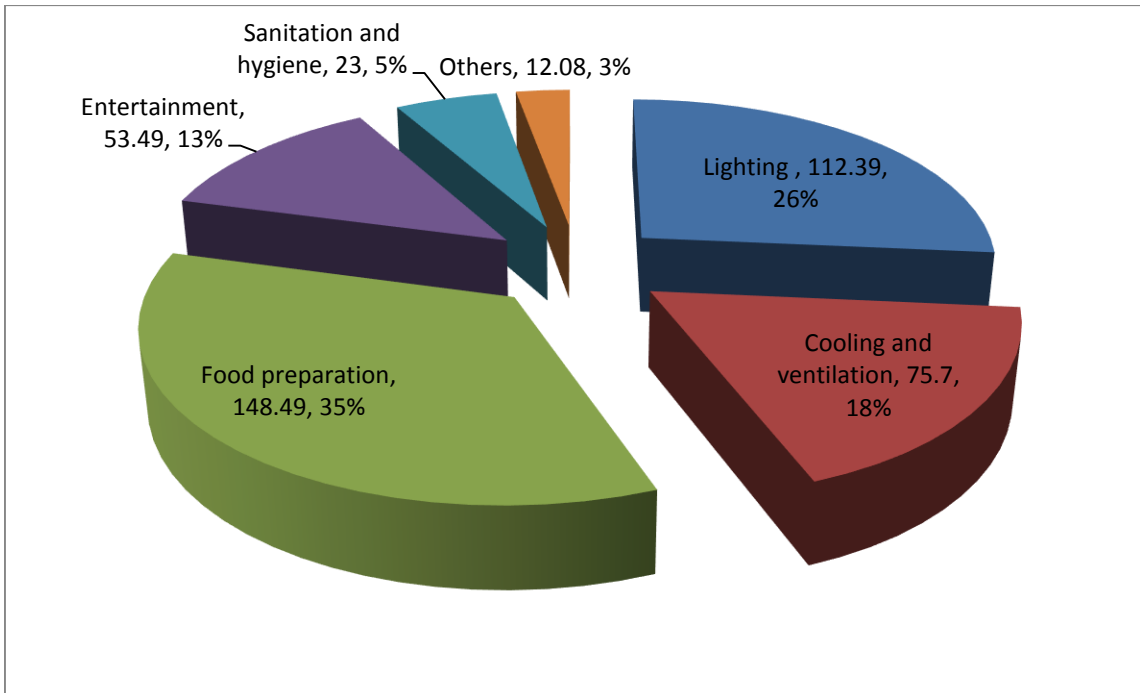


Figure 4.4: Indirect GHG Emissions from households by energy use category

The opportunities offered by these activities to the mitigation of household CO₂ are directly related to their energy intensity and consequently the emissions they produce. The emissions presented in Figure 4.4 represent the indirect baseline emissions for the surveyed houses. They are so called because they form the basis for analysis of future emissions.

4.5.5 Regression Analysis for Determinants of CO₂ Emission from Use of A.Cs

The study investigated the relationship between the level of CO₂ emission (E) by A.Cs and a number of variables including the number of units owned by each household (N), average number of days they are operated weekly (D) and number of hours operated daily (H). The results of the multiple regression analysis are shown in Table 4.21.

Table 4.21: Multiple Regression Analysis for Energy Consumption by A.Cs

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.93437728
R Square	0.8730609
Adjusted R ²	0.86863279
Standard Error	8.87976906
Observations	90

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	-49.217335	3.297917598	-14.923761	1.364E-25	-55.7733781	-42.6612917
N	10.1730164	0.914561612	11.12338	2.493E-18	8.354928053	11.9911047
D	5.88892988	0.570321757	10.3256272	9.986E-17	4.755167747	7.02269201
H	5.75772921	0.69354313	8.30190504	1.294E-12	4.379011094	7.13644732

A correlation coefficient (multiple R) of 0.9344 shows a strong positive linear relation between E and the independent variables. The coefficient of determination (Adjusted R²) of 86% shows that 86% of the variations of E-values around the mean are explained by the independent variables. All the parameters in Table 4.21 have very low P-values suggesting

Table 4.22: Summary of energy consumption and emission data for the surveyed houses

S/no	Metric	Value
1	Number of surveyed households	206
2	Average population of households	6 people
3	Average size of houses (area occupied)	85m ²
4	Energy intensity per household (grid electricity)	5954kWh/household/year
5	Energy intensity per capita (grid electricity)	992kWh/capita/year
6	Energy intensity per area (grid electricity)	70.05kWh/m ² /year
7	Carbon intensity per household (indirect)	2063.83kg
8	Carbon intensity per capita (indirect)	343.97kgCO ₂ /capita/year
9	Carbon intensity per area (indirect)	24.38kgCO ₂ /m ² /year
10	Carbon intensity per household (direct)	5660kg
11	Carbon intensity per capita (direct)	943.33kgCO ₂ /capita/year
12	Carbon intensity per area (direct)	66.59 kgCO ₂ /m ² /year
13	Carbon intensity per household (combined)	7723.83kg
14	Carbon intensity per capita (combined)	1287.30kgCO ₂ /capita/year
15	Carbon intensity per area (combined)	90.87 kgCO ₂ /m ² /year

These are the baseline energy consumption and emission data against which the future trends were compared. This study only estimated the emissions from household energy use activities i.e. consumption of grid electricity and burning of fossil fuels to generate energy for domestic use. What this implies is that the average emissions (1287.30kg/capita or 1.29tons/capita) from the household activities alone in the surveyed houses exceed the

figure for the various listed activities in Nigeria in 2011 suggesting that Kaduna metropolis is a high emission area in the Nigerian context.

4.5.7 Comparison of per capita CO₂ emission with other Countries

Table 4.23 is a comparison of building use per capita CO₂ emission of the study area and other world regions. The data for 2002 as given by Baumert *et al* (2005) were projected forwards to get the emissions for the current year. Baumert *et al* (2005) observed that new constructions are a strong indicator of future emission trends and this is projected to grow by 7% per annum in China as against the projected annual growth of 5% in India and Southeast Asia and 2% in the U.S., Western Europe and Japan. These projected growths in new construction for the various regions of the world were directly applied to the projection of the emissions in Table 4.23 because of the strong relationship between them.

Table 4.23: Comparison of Per Capita CO₂ Emissions from Building Use

Countries	Tons of CO ₂ per capita	
	2002	2015
U.S.	7	9.05
Germany	3.8	4.91
U.K.	3.5	4.53
Japan	3.1	4.01
South Africa	1.3	2.47
China	0.5	1.22
Indonesia	0.4	0.75
Nigeria (Kaduna)	N/A	1.29

The calculation of the 2015 household emission for South Africa was done using the estimated growth rate for Indonesia since it is the closest to South Africa in development indices. China was not considered because of the disproportionately high population difference between the two of them. It should be noted that the estimated emissions for the other countries are those associated with building use generally which include the direct and indirect emissions associated with energy consumption as well as emissions from waste generation but the emission calculated for Kaduna metropolis considered only the direct and the indirect energy use emissions and that the emissions from waste generation and transportation has not been included. An inference that could be drawn from this is that the level of emissions in Kaduna metropolis is by far greater than the average estimate (0.5metric tonnes) for Nigeria in 2011 and it may soon surpass that from some cities in the countries listed in Table 4.23.

4.6

Emissions for the Forecast Years

The years for which GHG emissions have been forecasted are 2020, 2035 and 2050. These forecasts were done from the baseline year 2015. The emissions from the households can be affected by many different factors and numerous interplays between them. Different scenarios of emissions of GHG were considered bearing in mind the possible interactions between the factors.

Two emissions scenarios have been considered in the estimation of future GHG emissions from the studied households. These are the baseline or reference scenario (or business as usual scenario) and a reduction case or alternative policy scenario as defined by the International Energy Agency (IEA, 2006) in Anderson et al (2008).

4.6.1 Business as usual scenario (BAU)

The business as usual scenario assumes that there are no changes from the status quo in relation to energy use patterns and emission mitigation policies. That is energy use and other activities that contribute to emission of GHGs will continue to be embarked upon in the future as they are done presently. No definite measures will be taken towards mitigation of emissions. Emissions were estimated for two BAU scenarios namely case A and case B.

4.6.1.1 Direct Emissions (DEs)

The case A for direct emissions is modeled after UNFCCC's observation that the emission of CO₂ from consumption of fossil fuels has been growing at 1.9% annually and the Case B adopted the 3% annual population growth rate for Kaduna state. The results are presented in tables 4.24 and 4.25 respectively.

Table 4.24: Projected Direct Emissions for the Business as usual Scenario (Case A)

Activity	Baseline emissions (tCO ₂ /year)	Forecasted Emissions (tCO ₂ /year)		
		2020	2035	2050
Use of power generators	397.75	437.00	579.55	768.61
Cooking with kerosene	27.90	30.65	40.65	53.91
Cooking with LPG	40.95	44.99	59.67	79.13
Cooking with biomass	418.77	460.09	610.18	809.23
Total	867.37	952.96	1263.83	1676.10

Table 4.25: Projected Direct Emissions for the Business as usual Scenario (Case B)

Activity	Baseline emissions (tCO ₂ /year)	Forecasted Emissions (tCO ₂ /year)		
		2020	2035	2050
Use of power generators	397.75	461.10	718.38	1119.21
Cooking with kerosene	27.90	32.34	50.39	78.51
Cooking with LPG	40.95	47.47	73.96	115.23
Cooking with biomass	418.77	485.47	756.35	1178.36
Total	867.37	1005.52	1566.57	2440.66

4.6.1.2 Indirect Emissions (IEs)

Applying the 1.6% emission growth rate per annum to the baseline emissions, the forecast years indirect emissions are as presented in Table 4.26 (Case A). Alternatively if the estimated 3% annual growth rate in the population of Kaduna state is applied, the emissions will be as presented in Table 4.27 (Case B).

Table 4.26: Projected Indirect Emissions for the Business as usual Scenario (Case A)

Activity	Baseline emissions (tCO ₂ /year)	Forecasted Emissions (tCO ₂ /year)		
		2020	2035	2050
Food preparation	148.49	160.76	203.98	258.81
Cooling and ventilation	75.70	81.96	103.98	131.94
Lighting	112.39	121.67	154.38	195.89
Entertainment	53.49	57.91	73.48	93.23
Sanitation and hygiene	23.00	24.90	31.59	40.09
Others	12.08	13.08	16.61	21.05
Total	425.15	460.27	584.00	741.01

Table 4.27: Projected Indirect Emissions for the Business as usual Scenario (Case B)

Activity	Baseline emissions (tCO ₂ /year)	Forecasted Emissions (tCO ₂ /year)		
		2020	2035	2050
Food preparation	148.49	172.14	268.19	417.83
Cooling and ventilation	75.70	87.76	136.72	213.01
Lighting	112.39	130.29	202.99	316.25
Entertainment	53.49	62.01	96.61	150.51
Sanitation and hygiene	23.00	26.66	41.54	64.72
Others	12.08	14.00	21.82	33.99
Total	425.15	492.87	767.87	1196.31

4.6.2 Alternative policy scenario (APS)

The alternative policy scenario is based on the assertion by IPCC (2010) that avoiding the worst impacts of climate change will necessitate the reduction of global CO₂ emissions by at least 50% by 2050. This can be achieved if the energy management measures suggested are adhered to by households. The baseline direct and indirect emissions for 2015 in Table 4.18 and Figure 4.3 were first projected forward to 2050 to get the emissions for that year (tCO₂/year) before interpolating for the intermediate years 2020 and 2035. The results are presented in Tables 4.28 – 4.31.

Table 4.28: Alternative Policy Scenario Direct Emissions from the Surveyed Houses (A)

Activity	Baseline emissions (tCO ₂ /year)	Forecasted Emissions (tCO ₂ /year)		
		2020	2035	2050
Use of power generators	397.75	424.24	503.71	583.18
Cooking with kerosene	27.90	29.76	35.33	40.91
Cooking with LPG	40.95	43.68	51.87	60.04
Cooking with biomass	418.77	446.66	530.33	614.00
Total	867.37	944.34	1121.24	1271.74

Table 4.29: Alternative Policy Scenario Direct Emissions from the Surveyed Houses (B)

Activity	Baseline emissions (tCO ₂ /year)	Forecasted Emissions (tCO ₂ /year)		
		2020	2035	2050
Use of power generators	397.75	449.28	603.88	758.48
Cooking with kerosene	27.90	31.52	42.37	53.21
Cooking with LPG	40.95	46.25	62.17	78.09
Cooking with biomass	418.77	473.03	635.80	798.57
Total	867.37	1000.08	1344.22	1653.91

Table 4.30: Projected Indirect Emissions for the Alternative Policy Scenario (A)

Activity	Baseline emissions (tCO ₂ /year)	Forecasted Emissions (tCO ₂ /year)		
		2020	2035	2050
Food preparation	148.49	156.37	180.01	203.65
Cooling and ventilation	75.70	79.72	91.78	103.82
Lighting	112.39	118.35	136.24	154.14
Entertainment	53.49	56.33	64.84	73.36
Sanitation and hygiene	23.00	24.22	27.89	31.55
Others	12.08	12.72	14.63	16.55
Total	425.15	447.71	515.40	583.08

Table 4.31: Projected Indirect Emissions for the Alternative Policy Scenario (B)

Activity	Baseline emissions (tCO ₂ /year)	Forecasted Emissions (tCO ₂ /year)		
		2020	2035	2050
Food preparation	148.49	167.73	225.45	283.16
Cooling and ventilation	75.70	85.51	114.94	144.36
Lighting	112.39	126.95	170.64	214.32
Entertainment	53.49	60.42	81.21	102
Sanitation and hygiene	23.00	25.98	34.92	43.86
Others	12.08	13.63	18.29	22.95
Total	425.15	480.23	645.48	810.73

4.6.3 Comparison of the Emission Scenarios

Figure 4.5 is a plot of the quantities of CO₂ emissions from the surveyed houses for the business as usual scenarios A and B and the alternative policy scenarios A and B. The gap between the highest emitting scenario, BAU (B) and the lowest emitting scenario, APS (A) is an indication of the possible scenarios of emissions under varying circumstances. As has been stated earlier, the forecast of likely emission path by any community is a very challenging task as the emissions are affected by many factors and these factors can play out in many different ways in the future that cannot be exactly predicted at present. The real path of the future emissions will be dictated largely by the trend of population and gross domestic product growth, and energy use policy pursued by the community as these have been identified from existing literature to be the key drivers of emission growth.

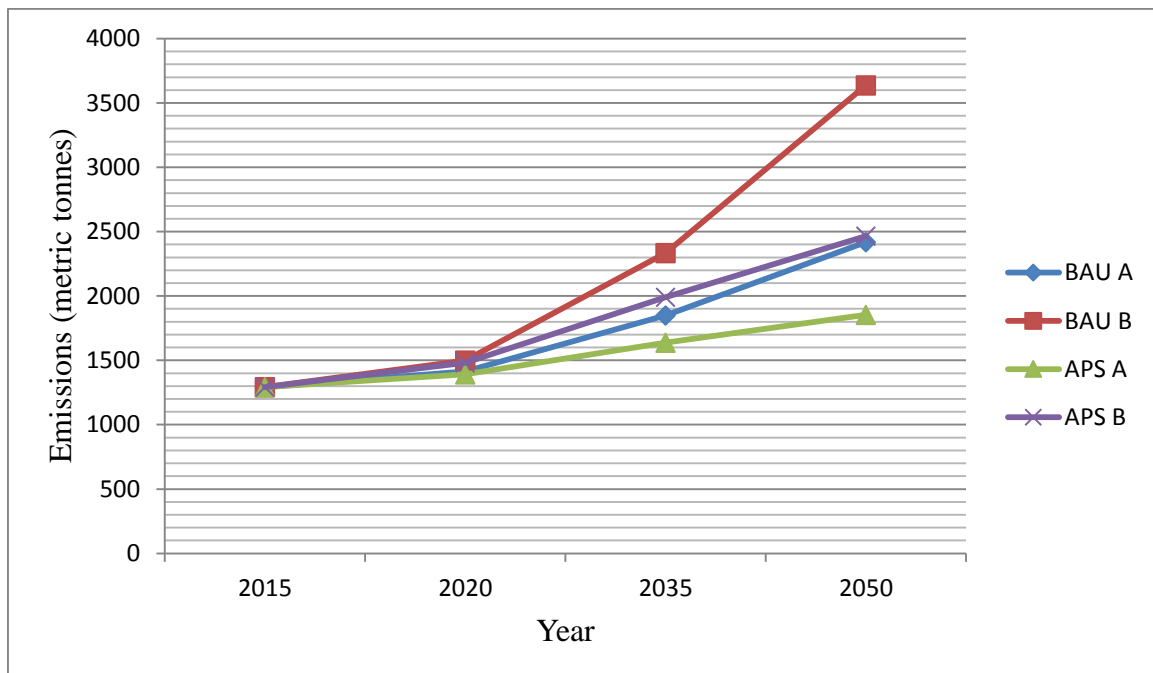


Figure 4.5: Business as usual and Alternative Policy Scenario CO₂ Emissions

The most realistic of the emission scenarios is the one that considered the population growth rate (BAU B) of the concerned community as one of the main determinants of the likely future emissions. This scenario is also responsible for the greatest emission. As can be seen from Figure 4.5 if the population of Kaduna metropolis and by extension those of the surveyed houses continue to grow at the rate of 3% (as was observed from 2006 census) into the future and the energy use pattern in the surveyed houses also follow the current trend, the emissions from these houses are likely to rise to about 3636.97 tCO₂ by 2050 from 1292.52 tCO₂ as at 2015. However if the emissions in Kaduna were to follow the average global trend of 1.9% annual growth in direct and 1.6% annual growth in indirect emissions, the trend will be as depicted by BAU (A) curve. This is not likely to present a true picture of the situation as the energy use behaviour and emissions differs widely between different communities due to differences in weather, level of affluence, available resources and physiologic needs.

The best CO₂ emission scenario is represented by the APS (A) which assumes that the emission of GHGs follows the average global trend into the future and that the households also begin to embrace the energy efficient measures as identified from the literature. Total emissions from the studied households are expected to be around 1854.82 tCO₂ by 2050 under the alternative policy scenario (A). APS (B) is a more likely scenario because of its relation with the population growth rate.

4.6.4 Analysis of Variance between the Emissions for the Forecast Years

An analysis of variance between the different emission forecast years was conducted to see if any statistically significant differences occur between them. The results are shown in Table 4.32.

Table 4.32: Results of the one-way ANOVA between Emission Scenarios

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
2020	4	5783.98	1445.995	2635.455
2035	4	7808.61	1952.153	85994.96
2050	4	10373.54	2593.385	560732

ANOVA

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Groups	2645171	2	1322586	6.110234	0.021071	4.256495
Within Groups	1948087	9	216454.1			
Total	4593258	11				

Since the P-value calculated (0.021071) is less than the cut-off for significance (alpha, $\alpha = 0.05$), it means that statistically significant differences exist between the means of the different emission scenarios for the various years for which the emissions were estimated. This implies that the null hypothesis (H_0) which states that no statistically significant differences exist between the means of the various emission scenarios is rejected and the alternative hypothesis (H_A) which says the means of CO₂ emissions from the different scenarios are different is accepted.

4.7

Measurement of Carbon Dioxide Concentrations

Concentrations of CO₂ emitted were measured during the household activities involving the use of fossil fuels. These activities are powering of generators with petrol, cooking with kerosene, LPG and biomass.

4.7.1 Concentration of CO₂ from Operation of Generators

The emission concentrations measured in parts per million (PPM) before (as benchmark) and during the operation of generators are as presented in Table 4.30.

Table 4.33: CO₂ Concentrations (PPM) Measured during Operation of Generators

N	Time	Outdoors				Indoors			
		Lowest	Highest	Mean	Corrected	Lowest	Highest	Mean	Corrected
72	Before	174	740	355	315-395	405	645	504	464-544
72	During	420	2997	1181	1122-1240	412	1642	625	585-665

N – Number of houses from which CO₂ concentrations were measured

Table 4.33 shows that the average outdoors concentration of CO₂ measured before the operation of the generators in the vicinity of the surveyed buildings is within the ASHRAE limit of between 300 and 400 ppm and also within the global average of 380 ppm. However this is not the case when the generators are in use as the average concentration computed during the operation of generators ranges between 1122 and 1240 ppm which is well above the stated limit. In view of this it can be said that the use of petrol to power generators discharges large quantities of CO₂ into the atmosphere. Consequently the use of generators

to augment domestic electricity needs is one of the ways households in Kaduna metropolis contribute to changes in global climate system as a sizable number of them own these generators. This is in addition to other numerous problems associated with the use of generators as identified by Stanley (2011) which include impaired hearing and visibility, sleeplessness, choking sensation, dizziness, self and public disturbance, heat generation and threat to other living organisms among others.

The corrected average indoor concentration of CO₂ measured during the operation of generators is below the ASHRAE limit of 1050 ppm despite the high concentrations outside. The difference between the indoor concentrations measured before (504 ppm) and during (625 ppm) the operation of the generators is not commensurate with that outside. One probable interpretation to this is the diffusion of the high concentrations of the gas by the ambient air before its infiltration into the interior spaces. However the households need to adopt more environmentally friendly alternatives to generators such as solar home systems to supplement the supply of grid electricity as suggested by Abdulsalam (2014). A correlation analysis of the CO₂ concentrations measured before and during the operation of the generators shows a strong positive linear relationship (correlation coefficient, $r = 0.72877$).

4.7.2 CO₂ Concentrations from Cooking

The concentrations of CO₂ in the vicinity of and inside the buildings as measured before and during the process of cooking with the three commonest fuels are as presented in Table 4.34.

Table 4.34: Concentrations (PPM) of CO₂ from Cooking with Different Fuels

N	Time	Fuel type	Average CO ₂ Concentrations			SD
			Outdoors	Indoors	Source	
72	Before the process	LPG	313	356	356	36.64
72		Kerosene	369	324	327	41.29
72		Wood	420	286	698	51.05
72	During the process	LPG	-	443	817	325.75
72		Kerosene	-	459	1002	790.20
72		Wood	-	410	1133	563.59

Table 4.34 shows that fuel wood produces the highest concentration of CO₂ (1133 ppm) within the vicinity of the activity (cooking). This confirms that the use of fuel wood for cooking is not a sustainable practice because apart from the destruction of forests which serve as home to a wide variety of species, a natural carbon dioxide sink is not only being destroyed but large quantities of the gas are also being released into the atmosphere to further inhibit the escape of infrared radiations from the earth surface into the outer space thereby aggravating the problem of global warming. Since most of the households that use wood do their cooking outdoors, it may also mean that the readings from the instrument are

an under-representation of the reality as there is most likely to be an easier and faster dispersion of the emitted gas particles into the atmosphere due to diffusion than would have been the case in an enclosed indoor environment.

LPG produces the least concentration of CO₂. It emits an average of 817 ppm of the gas as against the 1002 ppm produced from the use of kerosene as cooking fuel. Aside the problems of scarcity and odour associated with the use of kerosene, Lam et al (2012) observed that well-documented hazards associated with the use of kerosene are poisoning, fires and explosions as well as emission of substantial amounts of fine particulate matter, carbon monoxide (CO), oxides of nitrogen and sulfur dioxide.

The standard deviations (SD) of emissions computed for the various fuel types are relatively large indicating a large spread of the measured values from the mean. The consequence of this is that the mean is not likely to be a true reflection of the emissions from the various houses. That is there are wide variations in emissions from the various houses probably because of other emission producing-activities in the different neighbourhoods. Nonetheless the CO₂ concentrations measured in all cases are within the ASHRAE limit for a conducive indoor environment. Plates II to IV shows the process of measurement of CO₂ concentrations from some domestic activities.

4.7.3 Concentrations of Emissions in the Clusters

The average CO₂ concentrations measured in the different clusters are shown in Table 4.35. The reason for this is to observe if any marked differences exist between the clusters. The population density classifications of the clusters are as given by Kaduna state ministry of land, survey and country planning (2015).

Table 4.35: Average outdoor CO₂ concentrations in the different clusters

S/no	Clusters	Population density	CO ₂ Concentrations
1	Sabon Tasha	Low	351
2	Ungwan Romi	Medium	562
3	Barnawa	High	319
4	Nasarawa	Medium	331
5	Ungwan Rimi	Medium	311
6	Gabasawa	Medium	353
7	Tudun Wada	High	322
8	Bakin Ruwa	High	462
9	Kurmin Mashi	High	443
10	Ungwan Sarki	Medium	260
11	Kawo	High	348
12	Mando	Low	302

A look at the CO₂ concentrations reveals wide variations in concentrations between the clusters. The mean concentration calculated is 363.67 PPM while the standard deviation is

80.59 PPM. The implication of this is that most of the concentrations measured in the clusters are within the range of 283.08 PPM and 444.26 PPM which is relatively wide. The results of correlation analysis between the population densities of the clusters and the CO₂ concentrations shown in Table 4.36 indicate a weak positive linear correlation.

Table 4.36: Correlation of Population Density of Clusters and CO₂ Concentrations

	Population Density	CO ₂ Concentration
Population Density	1	
CO ₂ Concentration	0.214916	1

Table 4.36 shows that population density of the clusters and CO₂ concentrations in the clusters with a correlation coefficient of 0.21 are weakly positively correlated. This assertion follows from the guide provided by Hall (2012) for interpreting the results of correlation analysis.

4.8 The Greenhouse Gas Mitigation Framework

4.8.1 Philosophy behind the Framework

The underlying thinking behind the development of this framework is that of conservation and sustainability through the creation of a tool to guide the reduction of generation of CO₂ attributable to energy generation and consumption activities of residential buildings in Kaduna metropolis. This has been achieved through the review of relevant literature and collection and analysis of data on energy use and behaviour of households relating to the subject.

4.8.2 Development of the Framework

The framework proposed for mitigation of CO₂ from residential buildings as a result of energy use is presented in Figure 4.6. Mitigation of CO₂ from energy use in buildings can be achieved through energy efficiency of buildings which in turn can be accomplished through three main avenues namely good building design, efficient services design and behavioural modifications by building users.

Energy efficiency in buildings can be attained passively through the incorporation of efficient principles and equipment by the design professionals through the design of the building fabric and the technical infrastructure of the buildings which ensures their functionality. Behavioural modification refers to the deliberate change of attitude by the building users towards a more efficient use of the buildings and installed facilities and consequently a reduction of the negative impacts of the buildings on the environment.

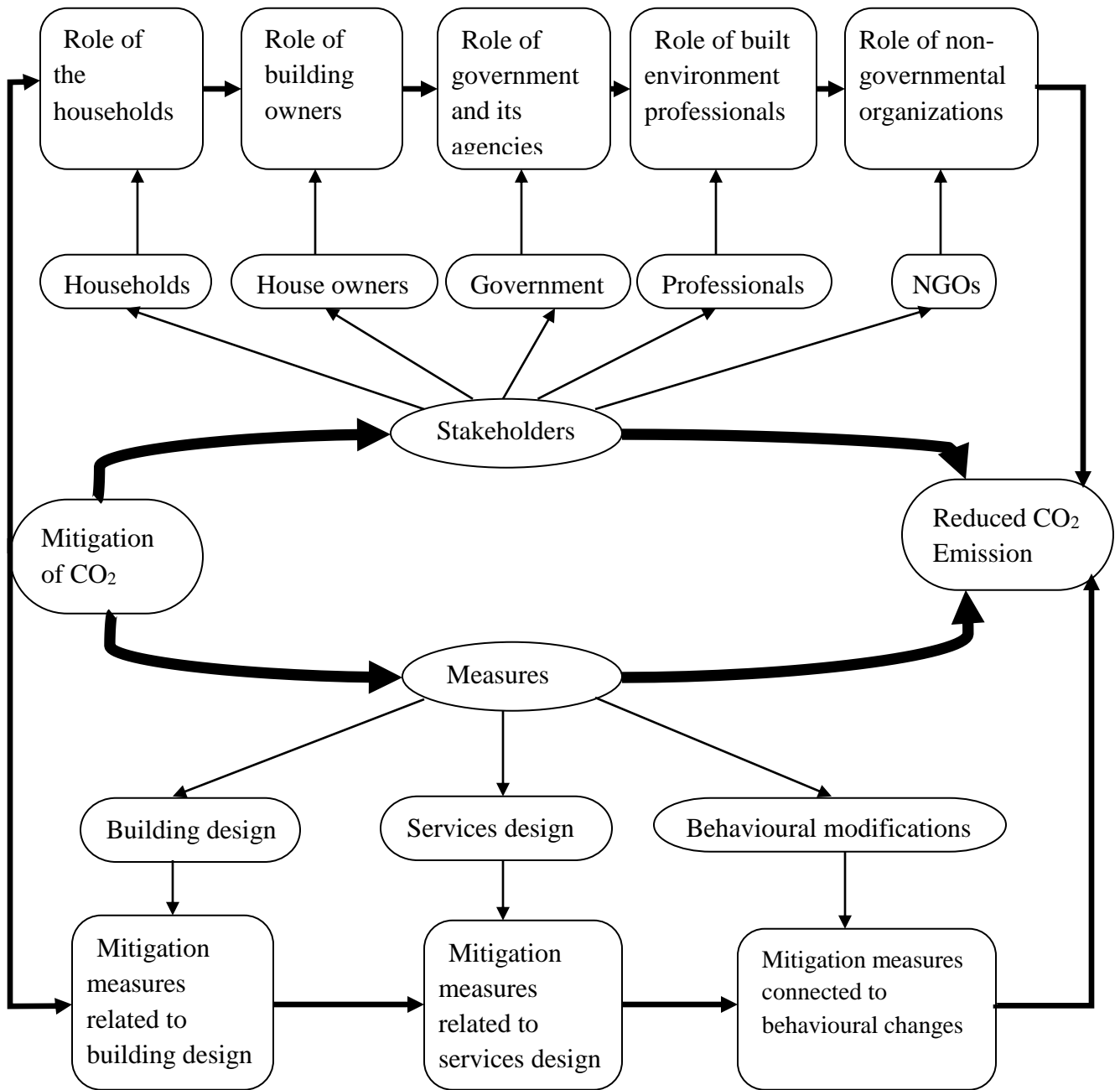


Figure 4.6: Framework for mitigation of CO₂ from Residential Buildings in Kaduna

Since CO₂ emissions are a direct consequence of energy consumption by domestic activities, proper understanding of energy consumption dynamics by households is vital to the development of the framework. This has already been achieved in the preceding

sections of this chapter. The energy consumed by the households is in two forms namely grid electricity generated from fossil fuel powered generation plants and direct combustion of fossil fuels and biomass on site by households. The measures for reduction of emissions from these various processes are as presented in the framework.

4.8.2.1 Mitigation Measures

To ensure the success of the mitigation framework, the following actions need to be taken by the concerned stakeholders:

Building Design: Residential CO₂ mitigation measures related to building design includes proper orientation of the buildings, specification of appropriate building materials considering the peculiarities of the environment, provision of adequate ventilation openings, correct building form and envelope, improving a building's air tightness, appropriate internal spatial layout, avoiding excessive glazing, use of shades and adherence to codes and standards. Other options to ensure proper design of buildings towards reduced energy consumption and CO₂ emissions are highlighted in the literature.

Services Design: Mitigation measures that can be achieved through services design mainly has to do with incorporation of energy efficiency into the buildings through specification and installation of correct equipment, reducing energy demand for ventilation, lighting and cooling, effective use of controls, mixed mode ventilation and incorporating natural lighting of interiors. Prospects of attainment of these measures are high because apart from

their environmental benefits, they are cheaper at least on the long term and people are becoming continuously more aware of them.

Behavioural Modifications: A comprehensive list of behavioural modifications through which households can significantly reduce their CO₂ emissions has been given in Table 4.16. Responses from the households indicate a low level of observance of these measures. It is believed that some advocacy can change the scenario. This view originated from the responses of the households on their readiness to adopt the suggested measures aimed at ensuring the energy efficiency of their buildings. Table 4.17 reveals a high level of readiness of the households to switch to the less CO₂ producing practices indicating that the attainment of this part of the framework is not likely to pose much of a challenge.

Figures 4.3 and 4.4 showed activities related to food preparation, lighting and cooling of the buildings to be the greatest energy consumers and consequently CO₂ emitters in the surveyed houses accounting for 35, 26 and 18% of the household CO₂ emissions respectively. Mitigation measures targeted at emission reduction from these activities must be pursued vigorously if significant reductions are to be attained. In the case of food preparation, the electric cooker, kettle, refrigerator and the water heater has been identified as the appliances consuming the greatest quantity of electricity. Upholding energy efficient measures related to use of these appliances can significantly reduce the emission of CO₂ from anthropogenic activities.

4.8.2.2 Stakeholders' Roles

The specific roles expected to be played by the various stakeholders identified in the framework to ensure reductions in CO₂ emissions are as follows:

Households: Households should contribute to reduction of CO₂ emissions through the following actions.

- a. Prudent use of resources through task lighting, switching light bulbs off when not in use, use of efficient cooking stoves and light bulbs.
- b. Substitution of wood and kerosene with LPG as the main cooking fuel.
- c. Use of smaller capacity petrol generators only when necessary to power light fittings and small electrical appliances.
- d. Installation of fewer numbers of air conditioners which should be operated only when absolutely necessary.
- e. Acquisition and use of solar home systems (SHS) for lighting and ventilation instead of petrol generators as an alternative energy source when the grid electricity is off.
- f. Retrofitting of filament and halogen lamps.
- g. Recording and monitoring of energy and other resources consumption

Building owners: The roles to be played by building owners in the mitigation of CO₂ emissions include the following-

- a. Provision of energy efficient housing.

- b. Seeking professional advice before embarking on projects.
- c. Understanding the needs of potential customers before embarking on projects.
- d. Use of appropriate materials as specified by the consultants.
- e. Adhering to standards in all aspects of building construction and operation.

Government: The government should engage in the following actions as ways of contributing to mitigation of CO₂ emissions-

- a. Awareness creation on energy efficiency in buildings.
- b. Ratification and pursuance of global climate change mitigation policies.
- c. Setting and implementation of emission reduction strategies.
- d. Immediate improvement in the power supply situation to obviate the need for households seeking alternatives.
- e. Emphasis on construction of renewable energy generation plants e.g. hydro, nuclear and solar power plants.
- f. Conservation of natural sinks (forests) and afforestation
- g. Provision of energy efficient housing
- h. Supporting households to acquire gas cookers and cylinders and subsidizing the cost of gas as is done in other countries.
- i. Legislation against the use of wood for cooking

Built environment professionals: The following are some roles that should be played by the built environment professionals including the designers, builders and town planners.

- a. Proper design to reduce the need for artificial cooling and lighting through correct specification of materials and equipment and correct orientation of buildings.
- b. Correct sizing, installation and operation of equipment.
- c. Advocacy of energy efficient practices.
- d. Adherence to codes and standards in the design and construction of building and associated facilities.
- e. Collaboration to provide a data repository and ongoing analysis of the climate impact of buildings.

Non-governmental organizations: Below are some of the roles that will be played by non-governmental organizations towards mitigation of CO₂ emissions from residences-

- a. Awareness creation on climate change mitigation measures.
- b. Involvement in dissemination of climate friendly energy technologies.
- c. Advocacy of energy efficient practices
- d. Creation of new GHG sinks through tree planting campaigns.
- e. Help communities adopt climate-friendly behaviours and lifestyles.
- f. Help monitor quality assurance and standards of low GHG emissions building performance.

CHAPTER FIVE

5.0 SUMMARY OF FINDINGS, CONCLUSION AND RECOMMENDATIONS

5.1 Summary of Findings

The major findings from the study are as summarized below:

- i. The commonest types of houses are those on separate compounds (33.98%), flats in blocks of flats (28.16%) and semi-detached houses (16.02%) while the average size of the houses is 85m² floor area and 6 full-time occupants.
- ii. The grid electricity is the main source of energy for lighting (83.50%), water heating (60.68%) and operation of entertainment equipment (70.87%) among the surveyed households.
- iii. There is a high rate of ownership of electrical equipment among the surveyed households but a relatively high number of these equipment are inefficient (specifically filament bulbs) or inefficiently operated.
- iv. The petrol generator is the main source of on-site electricity in the surveyed houses (75.24%). Most of the generators are rated 2 to 2.5 kVA and are operated an average of four hours/day for four days a week and consumes an average of 5 litres per day.
- v. Wood is the fuel consumed the most (1701kg annually) on-site by the surveyed households. This is followed by petrol (770kg) and LPG (131.40kg). The use of these fuels also emits the largest quantities of CO₂ from the households.
- vi. Gas cookers are the most preferred by the households for cooking. This is followed by electric cookers and kerosene stoves while cooking with biomass is the least desired.
- vii. The level of observance of energy efficiency measures by the households is generally low. However, there is high level of willingness to adopt suggested modifications in behaviour towards energy efficiency.

- viii. Cooking, lighting and cooling respectively consume the greatest quantity of grid electricity and also emit the most CO₂.
- ix. The direct emissions of CO₂ from the surveyed households are more than twice the indirect emissions and significant differences exist between the emissions from the different scenarios.
- x. The outdoor concentration of CO₂ during the operation of generators is beyond the ASHRAE limit while indoor concentrations are within the limit. In the case of cooking fuels, wood produced the greatest CO₂ concentration at the source of the emission followed by kerosene and LPG.
- xi. There is a weak positive linear relationship between the population density of the neighbourhoods and the CO₂ concentrations.

5.2

Conclusion

The commonest types of houses surveyed are houses on separate compounds and flats in blocks of flats. Since a reasonable percentage of the households surveyed live in rented houses, this may be an indication of house ownership needs in the city. The main factors contributing to the relatively high levels of emission of carbon dioxide as a result of energy use for domestic purposes in Kaduna metropolis are high population size of the households, possession of a variety of electrical appliances by the households, inefficient operation of these appliances and consumption of large quantities of fuel wood and fossil fuels.

The projected alternative policy scenario emissions were observed to be substantially lower than the business as usual scenario emissions suggesting that if the measures identified in the framework are seriously implemented by the stakeholders a reasonable reduction in emission of CO₂ can be achieved. Some advocacy can enlighten the surveyed households about the benefits derivable from climate change mitigation. The quantities of carbon

dioxide emitted from the burning of fossil fuels can be avoided or at least significantly reduced by households if they switch to the use of solar energy for their needs like lighting and operation of equipment as well as prudence in the use of energy for various domestic activities. The encouragement of the households by government and non-governmental organizations to adopt LPG as the main cooking fuel can also greatly reduce the emissions and other health hazards due to cooking with fossil fuels and biomass.

The identified household energy use activities produced large concentrations of CO₂ and the pursuance of the relevant mitigation measures by the concerned stakeholders can go a long way in achieving considerable emission reductions. This is in view of the fact that the households indicated some willingness to accept the suggested behavioural modifications.

5.3 Recommendations

The following are the recommendations from the study:

- a. The generation, transmission and distribution of electricity should be urgently improved by the concerned government agencies.
- b. Government should legislate on the use of energy saving electrical equipment in the country through its relevant agencies.
- c. Households should be enlightened by the relevant government agencies and NGOs on the dangers to the global climate system of using fossil fuels for on-site electricity generation and the benefits derivable from the use of solar energy.

- d. Households should be encouraged and supported by government and well-meaning and capable individuals to acquire and use gas cookers as against kerosene stoves and biomass for cooking. The cost of gas should also be subsidized for domestic users.
- e. There should be awareness creation by the government, non-governmental organizations and well-meaning individuals among households on the need for them to embrace energy efficiency measures.
- f. Households should avoid wasteful use of energy and other resources.

5.4 Areas for Further Studies

It is suggested that further studies be conducted in the following areas:

- a. Development of models that can be used to predict CO₂ emissions from energy use in buildings and also to estimate possible emission reductions.
- b. Determination of country specific emission factors for the various processes in buildings and associated fuel types in Nigeria.

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APPENDICES

Appendix 1: The Questionnaire

DEPARTMENT OF BUILDING,
FACULTY OF ENVIRONMENTAL DESIGN,
AHMADU BELLO UNIVERSITY, ZARIA

FRAMEWORK FOR RESIDENTIAL GREENHOUSE GAS MITIGATION IN KADUNA METROPOLIS

Questionnaire

Kindly respond to the questions below, giving as accurate as possible the information requested. The work is a Ph.D. research and any information given will be treated confidentially and for academic purpose only. Tick or fill in your response as appropriate. Please note that the durations of use of appliances requested are averages. Any item or question that does not apply to your household should be left as it is.

Property Record

1. Reporting
year_____
2. Which of the following best describe the type of your housing unit?

House on a separate yard [<input type="checkbox"/>]	Traditional/hut structure [<input type="checkbox"/>]
Flat in a block of flats [<input type="checkbox"/>]	Semi-detached house [<input type="checkbox"/>]
Rooms/let in house [<input type="checkbox"/>]	Improvised dwelling [<input type="checkbox"/>]
3. Street address (optional)_____
4. Neighbourhood

5. Year constructed (if known)_____

6. Size of the building Length _____ Width _____
7. Total number of full-time occupants 1-3 [] 4-7 [] 7-10 [] above 10 []
8. Is the house owned or rented? Owned [] Rented []

Building Energy Consumption Data

General

What are the main sources of energy for each of the following household end uses? Please indicate by marking the appropriate box.

Energy sources	Some household end uses of energy					
	Lighting	Cooking	Water heating	Entertainment	Grinding	Washing
Grid electricity						
Kerosene						
Petrol						
Diesel						
Charcoal						
Gas						
Power generator						
Firewood						
Solar PV system						
Dung						
Sawdust						

The following is a checklist of energy consumption activities at home and the appliances used together with the frequency of use. You are requested to kindly and carefully go through the list and indicate by filling in or ticking as applicable.

Ventilation

- Number of fans in your house.
1 [] 2 [] 3 [] 4 [] 5 [] 6 [] 7 []
- Please indicate how many are standing, ceiling or wall mounted fans.

Standing _____ Ceiling _____ Wall _____

3. Average daily duration of use of each fan.
 1-3 hours [] 4-6 hours [] 7-9 hours [] 10-12 hours []
 13-15 hours [] Over 15 hours []
4. Average number of days of use of each fan in a week.
 No more than 3 days [] 4 days [] 5 days [] More than 5 days []
5. Do you have any fan powered by a means other than electricity? Yes [] No []
6. If your response to question 5 above is yes, what is used in powering the fan?
 Solar energy [] Kerosene [] Others, please specify _____

Cooling

1. Do you have air conditioner(s) in your house? Yes [] No []
2. Number of air conditioners. 1 [] 2 [] 3 [] 4 []
3. How many days in a week on the average do you operate each of the air conditioners?
 1 [] 2 [] 3 [] 4 [] 5 [] 6 [] 7 []
4. What is the average duration of use in hours?
 1-2 [] 3-4 [] 5-6 [] over 6 []

Food Preparation and Cooking

Kindly provide the requested information for each of the following as used in your house.

Appliances	Number of times used daily	Average duration of use (hours)
Electric cooker		
Electric kettle		
Water heater (ring)		
Blender		
Toaster		
Microwave oven		
Dishwasher		
Refrigerator		
Freezer		

Lighting

Please indicate by marking in the response column the ones you have among the following items.

Types of light bulbs	Response	Quantity	Average hours of use per day
Tungsten filament bulbs			
Fluorescent tubes			
Compact fluorescent bulbs			
Halogen lamps			
Light emitting diodes			

Do you practice task lighting? Yes [] No []

If you practice task lighting, what is the motivating factor for this?

Money saving [] Energy saving [] Sustainability [] All []

How often do you switch off the lights in unoccupied rooms/spaces?

Always [] More often than not [] Rarely [] Never []

Entertainment

Please indicate by ticking the response column the ones you have among the following systems.

System/equipment	Response	Average daily frequency of use (hours)
Television		
DVD player		
Hi-Fi system		
Cassette recorder		
Stereo system		
Satellite decoder		

Laundry

Equipment	Frequency of use (days in a week)	Duration of use (hours)
Washing machine		
Clothes dryer		
Electric iron		

Sanitation and Hygiene

Equipment	Frequency of use (days)	Duration of use (hours)
Water heater		
Hair shaver		
Hair dryer		
Vacuum cleaner		

Other household appliances

Equipment	Weekly use (days)	Daily use (hours)
Desktop computer		
Laptop computer		
Printer		
Scanner		
Water pump		

Onsite Energy Generation and Consumption

1. Kindly indicate if you use any of the following for electricity generation at home.

Petrol powered generator []

Diesel powered generator []

Solar panels []

Wind mills []

2. If you have a generator, what is the power rating of the generator?

650VA [] 700VA [] 2.0KVA [] 2.5KVA [] 5.0KVA []

3. How often do you operate the generator on the average weekly?
 Everyday [] Every other day [] Twice [] Once []
4. How long on the average does each cycle of operation of the generator last?
 0-1 hour [] Over 1 hour-less than 2 hours [] 2-3 hours []
 Over 3 hours-less than 5 hours [] 5 hours and above []
5. The average amount of fuel consumed each time the generator is operated.
 Less than 2 litres [] 2-5 litres []
 More than 5 but less than 10 litres [] More than 10 litres []

Energy use for Cooking

1. Indicate all the options used for cooking and water heating in your house
 Kerosene []
 Cooking gas []
 Firewood []
 Charcoal []
 Sawdust []
2. What is the quantity of kerosene consumed in your house each month?
 Less than one gallon [] One gallon []
 Less than two gallons [] Two gallons []
 Less than three gallons [] Three gallons
3. If you use gas, what is the size of your cylinder?
 3kg [] 6kg [] 12.5kg [] 47.5kg []
4. How long does it take you before refilling the gas cylinder?
 2 weeks [] 3 weeks [] 4 weeks [] 5 weeks []
 Others, please specify _____
5. How many bundles of firewood do you use every day?
 1 [] 2 [] 3 [] 4 [] 5 [] 6 [] 7 [] 8 []
6. How much on the average do you spend on purchasing firewood daily?

50 naira [] 60-100 naira [] 101-200 naira [] 201-300 naira []

7. How many sacks of charcoal do you use every month?

1 [] 2 [] 3 [] 4 [] 5 [] 6 []

8. How many sacks of sawdust do you use every month?

1 [] 2 [] 3 [] 4 [] 5 [] 6 []

9. If given an option, kindly rank your preference of energy technology/type for cooking. Use a rank of 1-5 where 1 is the most preferred and 5 is the least preferred.

Energy technology	Preference				
	1	2	3	4	5
Electric cooker					
Gas cooker					
Kerosene stove					
Fire wood					
Saw dust stove					
Charcoal stove					
Dung					

Energy Use Behaviour and Behavioural Adaptations

1. How would you rate your level of awareness of the concept of energy efficiency?

Very high [] High [] Low [] Very low [] Not aware []

2. What is the level of your observance of the following energy efficient measures?

Select by ticking (√) on a scale of 1-5 where

1-Very high 2 - High 3 - Low 4- Very low 5 - Does not observe

S/no	Energy efficient measures	Level of observance				
		1	2	3	4	5
1	Closing exterior doors and windows when the AC is on					
2	Changing or cleaning AC's air filters at least once a month					
3	Using shades and blinds to prevent overheating by the sun					
4	Changing inefficient AC systems to more efficient ones					
5	Use of fans to circulate cooled air					
6	Using ceiling fans to cool off for less					
7	Replacing incandescent bulbs with compact fluorescent lamps					
8	Using timers to turn lights on and off at the right times					
9	Use microwaves and toaster ovens instead of usual ovens					
10	Replacing old refrigerators					
11	Air drying clothes as against machine drying					
12	Keeping the oven door closed while cooking					
13	Matching the pot size to the burner on the stove					
14	Using tight-fitting covers on pots and pans when cooking					
15	Washing with cold water instead of hot water					
16	Use of solar water heater for energy saving					
17	Full loading of washing machine when washing					
18	Unplugging battery chargers when they are not in use					

3. Kindly indicate to what extent you are willing to accept the following measures/behavioural modifications being suggested towards the reduction of energy use and consequently lower greenhouse gas emissions. Base your choice on a scale of 1-5 where 1 is very high willingness, 2 is high willingness, 3 is low willingness, 4 is very low willingness and 5 is not willing.

S/no	Behavioural changes	Frequency				
		1	2	3	4	5
1	Turn off lights and appliances when not in use					
2	Task lighting instead of general overhead lighting					
3	Use daylight for reading, working and living					
4	Use of lighter colours on walls and ceiling					
5	Replace all incandescent bulbs with energy saving types					
6	Keep lights and lighting fixtures clean					
7	Reduce heat gain by planting trees and shrubs around the building					
8	Ensure food is cool and covered before it goes into the refrigerator					
9	Clean the reflectors underneath the burners on stovetops					
10	Fill the freezer by using bottles filled with water for empty spaces					
11	Replacing appliances over ten years old with newer models					
12	Improve lighting controls by using occupancy sensors and timers					
13	Clean cooling coils on a regular basis					
14	Installation of renewable energy technologies					
15	Switching from electricity to solar water heating					
16	Switching from the conventional roofing system to cool roofs					

Appendix 2: Power Ratings of Common Household Appliances

S/No	Appliances	Power Rating (Watts)
1	Air conditioner (room)	1000
2	Air conditioner (central)	2000-5000
3	Blender	300
4	CD Player	15-30
5	Ceiling Fan	10-50
6	Laptop Computer	20-75
7	Desktop Computer	80-200
8	Printer	100
9	Dishwasher	1200-1500
10	Hot Plate	1200
11	Iron	1000
12	Microwave	600-1500
13	Refrigerator/freezer	500
14	Fluorescent lamp	20-40
15	Satellite Dish	30
16	Shaver	15
17	Sink Waste Disposer	450
18	Stereo	10-30
19	Table Fan	10-25
20	Toaster	800-1500
21	Vacuum Cleaner (upright)	200-700
22	VCR	40
23	Washing Machine	350-500
24	Chest Freezer (600 litres)	200
25	Energy saving lamp	10-20
26	Pumping machine	1000-1500
27	Water dispenser (cold/hot)	100/500
28	32 inch LCD TV	150
29	37 inch LCD TV	170
30	42 inch LCD TV	205
31	100 watts filament lamp	100
32	60 watts filament lamp	60
33	Electric kettle	2000

Appendix 3: Questionnaire Responses

Table 1: Frequency of Use of Kitchen Appliances

S/N	Appliances	No. of times used	Frequency
1	Electric cooker	1 (daily)	19
		2	48
		3 and above	49
2	Electric kettle	1 (daily)	58
		2	38
		3 and above	38
3	Water heater (ring)	1 (daily)	25
		2	23
		3 and above	15
4	Blender	1 (weekly)	69
		2	11
		3 and above	3
5	Toaster	1 (weekly)	25
		2	2
		3 and above	2
6	Microwave oven	1 (daily)	20
		2	2
		3 and above	1

Table 2: Average duration of use/cycle of use of kitchen appliances

S/N	Appliances	Duration of use	Frequency
1	Electric cooker	< 1 hour	3
		1 – 2	81
		> 2	32
2	Electric kettle	< 20 minutes	77
		20 – 30 minutes	56
		> 30 minutes	1
3	Water heater (ring)	< 20 minutes	63
		20 – 30 minutes	0
		> 30 minutes	0
4	Blender	1 – 5 minutes	20
		6 – 10 minutes	54
		> 10 minutes	9
5	Toaster	< 20 minutes	15
		20 – 40	10
		> 40	4
6	Microwave oven	< 20 minutes	6
		20 – 40	14
		> 40	3
7	Refrigerator	< 6 hours	22
		6 – 12 hours	59
		> 12 hours	58
8	Freezer	< 6 hours	13
		6 – 12 hours	35
		> 12 hours	18

Table 3: Average annual duration of use of kitchen appliances

S/no	Appliances	Average duration of use (hours)	Number of times used	Average annual duration of use (hours)
1	Electric cooker	1.5	2 daily	1095
2	Electric kettle	0.42	2 daily	306.6
3	Water heater (ring)	0.42	2 daily	306.6
4	Blender	0.13	2 weekly	13.52
5	Toaster	0.33	1 weekly	17.16
6	Microwave oven	0.5	1 daily	182.5
7	Refrigerator	9 (4.5)	-	1642.5
8	Freezer	9 (4.5)	-	1642.5

Appendix 4: Electricity Emission Factors

Emissions per kWh of electricity consumed			
Country	kgCO₂/kWh	kgCH₄/kWh	kgN₂O/kWh
Africa	0.840987822	0.00001341475	0.00000979663
Algeria	0.734684458	0.00001354854	0.00000143571
Australia	1.075886822	0.00001193717	0.00001495291
Brazil	0.109907407	0.00000211589	0.00000064114
Cameroon	0.239547303	0.00000716702	0.00000123759
Canada	0.196459189	0.00000245670	0.00000259486
Egypt	0.573425181	0.00001325914	0.00000188783
France	0.075693212	0.00000107817	0.00000069265
Germany	0.714637591	0.00000767552	0.00000967384
Ghana	0.237555181	0.00000972259	0.00000194452
Japan	0.465951477	0.00000746038	0.00000416633
Kenya	0.367555876	0.00001446107	0.00000289221
Malaysia	0.770701108	0.00001131957	0.00000695002
Mexico	0.548526273	0.00001242814	0.00000321603
Middle East	0.812802612	0.00002104355	0.00000403092
Morocco	0.80879585	0.00001440036	0.00001045466
Mozambique	0.000492252	0.00000000877	0.00000000088
Namibia	0.541773935	0.00000602866	0.00000851225
Netherlands	0.444453808	0.00000595357	0.00000308594
New Zealand	0.2139999	0.00000299077	0.00000160492
Nigeria	0.486277966	0.00001115868	0.00000156935
Norway	0.002455289	0.00000002945	0.00000000705
Oman	1.035857493	0.00002324486	0.00000317856
Pakistan	0.615374995	0.00001798722	0.00000316016
Philippines	0.60890161	0.00000935938	0.00000712544
Poland	1.279765701	0.00001339686	0.00001926536
Qatar	0.659619964	0.00001175793	0.00000117579
Russian Federation	0.562633284	0.00000811770	0.00000452463
Saudi Arabia	0.877366485	0.00002619636	0.00000451727
Senegal	0.66173706	0.00002563959	0.00000510815
Serbia	1.712876916	0.00001741407	0.00002577648
Singapore	0.614543486	0.00001409863	0.00000199201
Slovenia	0.626100978	0.00000642866	0.00000933121
South Africa	1.182936289	0.00001251850	0.00001875332
United Kingdom	0.548402315	0.00000728401	0.00000552340
United States	0.586666503	0.00000702729	0.00000776512
World	0.689697213	0.00000920111	0.00000869864

Source: Ecometrica (2011)

Appendix 5: Illustrations of the Empirical Study



Plate I: The CO₂/ Humidity/ Temperature Data Recorder and the CO₂ Sensor



Plate II: Measurement of outdoor concentration of CO₂ from a generator



Plate III: Measurement of CO₂ concentration during cooking with LPG



Plate IV: Measurement of CO₂ concentration during cooking with kerosene

