ESSAYS ON ALTERNATIVE ENERGY OPTIONS, ENVIRONMENT AND ECONOMIC GROWTH: THE CASE STUDY OF NIGERIA

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Dissertation presented for the Degree of Doctor of Philosophy in Development Finance in the Faculty of Economic and Management Sciences at Stellenbosch University

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DECLARATION

By submitting this thesis electronically, I, Emily Edoisa Ikhide, affirm that the totality of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third-party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

E.E. Ikhide December 2019

DEDICATION

I dedicate this to God who has made this possible, and to my son Jason Raymond Ezra, for all your love and support.

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ABSTRACT

The contribution of energy to the economic productivity of developed and developing countries has been a controversial topic in economic theory. The theoretical and empirical literature on the impact of energy on economic growth are inconclusive. Coupled with recent issues of global warming and climate change, rapid depletion of fossil fuels and increased energy demand for growth have increased debates and concerns on sustainable growth for the global economy. Therefore the study explored the relationship between alternative energy sources, economic growth and environmental quality with focus on the Nigeria economy. Specifically, the study addresses the following three questions: (a) what is the contribution of energy consumption (renewable and non-renewable) on economic growth in Nigeria? (2) Does economic growth influence environmental quality? (3) Does renewable energy compare with fossil fuels in terms of cost and benefits?

The results of the study have been organised into three empirical essays. The first empirical essay explored the impact of disaggregated energy consumption on economic growth in Nigeria. Results based on a bounds test cointegration analysis suggest that fossil energy use is a strong determinant of growth in the long run. From the results, a unit increase in fossil fuel energy consumption will lead to a 0.056 unit increase in economic growth, holding other factors constant. In terms of elasticity, a one per cent increase in fossil fuel energy consumption will lead to a 0.056 per cent increase in economic growth. This implies that fossil fuel energy consumption plays a significant role in increasing productivity of the economy and thereby driving economic growth, confirming the existence of the growth hypothesis in Nigeria. Contrary to a priori expectations, renewable energy consumption has a negative effect on economic growth in both the short and long run. The results show that a unit increase in renewable energy consumption, holding other factors constant, would reduce economic growth by 0.093 units in the long run. In terms of elasticity, this implies that a one per cent increase in renewable energy consumption will lead to a 0.093 per cent reduction in economic growth Aggregate energy consumption, however, has a positive effect on economic growth with a coefficient of 1.34, implying that a one per cent increase in energy consumption will increase economic growth by 1.34 per cent, holding other factors constant. This implies that policy should be focused on a comprehensive examination of an optimal energy portfolio to drive growth.

The second essay investigated the influence of economic growth on environmental degradation in Nigeria. The study employed yearly time series data from 1980-2016, using an ARDL bound testing approach to examine the long run linkages among energy consumption; economic growth and CO_2 *emissions in Nigeria. The results confirm the existence of a long run relation among the series and provided evidence in support of the Environmental Kuznets*

Curve (EKC) hypothesis in Nigeria. Estimates of the main parameters all have the expected signs. A positive effect is seen between GDP per capita and CO_2 emissions, while a negative effect of the squared GDP per capita to CO_2 emissions is found. This implies that as GDP moves beyond the Environmental Kuznets Curve turning point, environmental quality begins to set in. The result of the calculated threshold point of $1,862 GDP per capita implies that at the early stages of development, economic growth leads to increases in carbon emission up to a threshold of $1,862 GDP per capita after which the effect of economic growth on CO_2 switches to negative, hence further economic growth leads to decline in CO_2 emissions at the later stage of development. However, the observed threshold estimates suggest that the environmental degradation effect of GDP growth is bigger than environmental quality enhancement effect.

The third essay investigated the economic viability of energy options in Nigeria for financing an optimal energy portfolio. Cost benefit analysis using life cycle cost analysis and cost effectiveness analysis used to calculate the levelised costs were employed for the assessment of seven different technologies (gas, solar, wind, large hydropower, biomass, diesel-powered and coal). Based on these method, the life cycle cost and the levelised cost were also used as the criteria for choosing the most economically feasible energy options to be included in the energy portfolio, this was followed with a sensitivity analysis. The results clearly revealed that when the environmental effects are taken into consideration from a cost and benefit point of view, hydro, wind, solar and gas sources are the most competitive and viable options amongst the available energy resources. The findings of this essay have pertinent policy implications and suggest the need for a more integrated energy and growth policy.

On the whole, the study makes a unique contribution to the literature in three main ways. First, it is one of the first few studies to explore separately the effect of alternative (renewable and non-renewable) energy sources on economic growth in Nigeria. It showed that for a developing country such as Nigeria with large developmental gaps and slow growth in the midst of abundant renewable and conventional energy resources, the path to sustain growth and rapid development cannot be by fossil energy alone, rather a more careful approach of combined energy sources (renewable and non-renewable) would be necessary to achieve sustainable growth. This understanding is important for policy makers in focusing on a comprehensive examination of an optimal energy portfolio to drive sustainable economic growth and development. Second, the study examined the threshold effect of growth and the environment. By incorporating nonlinear terms we showed the turning point (threshold) of the relationship between economic activity and the quality of environment and confirm the shape of the relationship to support EKC in the case for Nigeria. In addition, we have shown that the net effect on the environment may be negative as the environmental degradation effect of growth

is larger than the environmental quality enhancement effect. This helps in rethinking policy strategies in enhancing growth and improving environmental quality at the same time. Finally, based on the establishment of the effects of energy consumption on economic growth and the environment, the economic viability of energy options (renewable and non-renewable) for a portfolio mix was assessed, taking into consideration Nigeria's rich energy (global energy force) and growth (it is one of the largest economy in Africa). Using a discounted cost benefit analysis by calculating the life cycle cost, and levelised cost analysis to arrive at the supply potential of multiple energy sources, this paper identifies viable energy options for Nigeria and proposes a portfolio of options which the country can consider in her energy production and use.

Keywords: *Renewable energy, Exhaustible Resources, Air Pollution, Environmental Impact and Energy, Nigeria*

Contents

DECLARATION ii
DEDICATION iii
ACKNOWLEDGEMENTS iv
ABSTRACT v
List of Acronyms and Abbreviations xii
List of Tables xvi
List of Figures xviii
CHAPTER ONE INTRODUCTION 1
1.1 Background of the study 1
1.2 Statement of research problem 4
1.3 The case for Nigeria 9
1.4 Research objectives of the study 10
1.5 Research questions 10
1.6 Rationale for each essay and significance of the study 10
1.7 Methodology 12
1.8 Contribution of the study 13
1.9 Outline of the thesis 15
CHAPTER TWO 16
ENERGY SECTOR DEVELOPMENT IN NIGERIA STYLISED FACTS AND OVERVIEW 16
2.1 Introduction 16
2.2 Historical development of the Nigerian energy sector 16
2.3 Energy sources and reserves 17
2.3.1 Natural gas 17
2.3.2 Crude oil 19
2.3.3 Other fossil energy sources 20
2.3.4 Renewable energy sources 20
2.3.5 Solar energy 21
2.3.6 Hydropower energy 21
2.3.7 Wind energy 22
2.3.8 Biomass 22
2.4 Energy structure and sectoral consumption in Nigeria 24
2.4.1 The residential sector 26
2.4.2 The industrial sector 26
2.4.3 The transport sector 26

2.4.4 The "Others" sector ... 27
2.5 Performance/contribution of the energy sector to the Nigerian economy ... 27
2.6 The electricity sector ... 29
2.7 Energy efficiency in Nigeria ... 31
2.8 Energy financing options in Nigeria ... 35
2.9 Energy sector policy reforms ... 37
2.10 Conclusion ... 39
References ... 40
CHAPTER THREE ENERGY, GROWTH AND THE ENVIRONMENT: A LITERATURE REVIEW ... 44
3.0 Abstract ... 44
3.1 Introduction ... 44
3.2 Energy-growth nexus ... 44
3.2.1 Literature on energy-growth nexus ... 44
3.2.2 The empirical literature on the link between energy and growth ... 47
3.2.3 Summary of literature review on energy-growth nexus ... 51
3.3 The Environmental Kuznets Curve (EKC) hypothesis ... 51
3.3.1 The empirical studies on EKC ... 55
3.3.2 Summary of literature review on the energy-growth-environment nexus 56
3.4 Literature on costs and benefits of energy options ... 57
3.4.1 Empirical literature on energy options ... 58
3.5 Summary of literature review ... 60
References ... 62
CHAPTER FOUR ALTERNATIVE ENERGY CONSUMPTION AND ECONOMIC GROWTH IN NIGERIA ... 72
4.0 Abstract ... 72
4.1 Introduction ... 72
4.2 Theoretical framework ... 76
4.3 Data source ... 76
4.4 Model specification ... 77
4.5 Estimation techniques and empirical analysis ... 78
4.5.1 Stationarity test ... 78
4.5.2 Cointegration analysis (bounds testing approach) ... 82
4.6 Conclusion and policy implications ... 88
References ... 89
CHAPTER FIVE ENERGY, ECONOMIC GROWTH AND CO_2 EMISSIONS IN NIGERIA ... 94

5.0 Abstract ... 94
5.1 Introduction ... 94
5.2 Theoretical framework ... 96
5.3 Data source ... 98
5.4 Model specification ... 99
5.5 Estimation techniques and empirical analysis ... 100
5.5.1 Stationarity test ... 100
5.5.2 Cointegration analysis (bounds testing approach) ... 101
5.6 Conclusion and policy implications ... 105
References ... 107
CHAPTER SIX AN ECONOMIC COST BENEFIT ANALYSIS OF ENERGY SOURCES IN NIGERIA ... 110
6.0 Abstract ... 110
6.1 Introduction ... 110
6.2 Sources of data ... 113
6.3 Theoretical framework ... 114
6.4 Estimation techniques and empirical analysis ... 115
6.5 Cost benefit analysis (CBA) ... 115
6.5.1 Costs and benefits identification, quantification and monetisation ... 116
6.5.2 Valuation and monetisation of benefits ... 116
6.5.3 Net Present Value (NPV) ... 117
6.6 Life-cycle cost analysis of energy options ... 117
6.6.1 Operating and maintenance costs ... 118
6.6.2 Replacement costs ... 118
6.6.3 Fuel cost ... 118
6.6.4 Environmental cost ... 119
6.7 Cost Effectiveness Analysis ... 119
6.7.1 Levelised cost of energy supply ... 119
6.7.2 Capacity factor ... 120
6.8 Sensitivity analysis ... 120
6.9 Empirical analysis ... 121
6.9.1 Calculation of life cycle cost of energy technologies ... 122
6.9.2 Environmental costs/benefits ... 122
6.9.3 Financial benefits ... 124
6.9.4 Employment benefits ... 126
6.9.5 Economic viability of energy options ... 127

6.9.6 Levelised cost of energy supply 128
6.9.7 Sensitivity analysis 129
6.10 Conclusion and policy implications 137
References 139
CHAPTER SEVEN CONCLUSIONS AND POLICY RECOMMENDATIONS 143
7.1 Summary of findings and conclusion 143
7.2 Contribution 145
7.3 Conclusions 147
7.4 Recommendations 148
7.5 Limitations of the study 149
References 150
Appendix A 156

List of Acronyms and Abbreviations

ADF	Augmented Dicky Fuller
ARDL	Autoregressive Distributed Lag
Bcf	billion cubic feet
BCR	Benefit Cost Ratio
b/d	barrels per day
BPE	Bureau of Public Enterprises
Btu	British thermal unit
CBA	Cost Benefit Analysis
CBN	Central Bank of Nigeria
CO_2	Carbon dioxide
CSP	concentrating solar power
CUSUM	Cumulative Sum
CUSUMsQ	Cumulative Sum of Squares
DISCOs	Electricity Distribution Companies
DME	Department of Minerals and Energy
ECA	Economic Commission for Africa
ECM	Error Correction Mechanism
ECN	Energy Commission of Nigeria
EESS	Electrical Energy Storage System
EIA	Energy Information Administration
EKC	Environmental Kuznets Curve
EEM	Energy Efficiency Measures
EPA	Environmental Protection Agency
EPSRA	Enactment of the Electric Power Sector Reform Act
ERGP	Economic Recovery Growth Plan
FEC	Federal Executive Council
FGN	Federal Government of Nigeria
FMP	Federal Ministry of Power
FMPWH	Federal Ministry of Power, Works and Housing
GDP	Gross Domestic Product
GDPPC	Gross Domestic Product Per Capita
GENCOs	Electricity Generation Companies

GHG	Greenhouse Gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GWh	Gigawatt
IBRD	International Bank for Reconstruction and Development
IMF	International Monetary Funds
IPCC	Intergovernmental Panel on Climate Change
IPPs	Independent Power Producers
IRENA	International Renewable Energy Agency
JICA	Japan International Cooperation Agency
KPMG	Klynveld Peat Marwick Goerdeler
$kWh/m^2/day$	kilowatt-hours per square meter per day
LCC	Life Cycle Cost
LCCA	Life Cycle Cost Analysis
LDCs	less developed countries
LNG	Liquefied Natural Gas
mBtu	million British thermal units
MCDM	Multiple Criteria Decision Making
MoU	memorandum of understanding
MPWH	Ministry of Power, Works and Housing
MW	Megawatt(s)
m/s	metres per second
MSW	Municipal Solid Waste
MYTO	Multi-Year-Tariff-Order
NAPTIN	National Power Training Institute of Nigeria
NASPA-CCN	National Adaptation Strategy and Plan of Action on Climate Change for Nigeria
NBS	National Bureau of Statistics
NDC	Nationally determined contribution
NCEEC	National Center for Energy Efficiency and Conservation
NDPHCN	Niger/Delta Power Holding Company
NEPA	National Electric Power Authority
NERC	Nigerian Electricity Regulatory Commission
NESP	Nigerian Energy Support Programme
NGC	New General Catalogue

NIPP	National Independent Power Project
NIMET	Nigerian Meteorological Agency
NNPC	Nigerian National Petroleum Corporation
NPV	Net Present Value
NRE	Non-renewable energy
NREEEP	National Renewable Energy and Energy Efficiency Policy
OCGT	Single Cycle Gas Turbines
ODF	Official Development Finance
OECD	Organisation for Economic Cooperation and Development
OFID	OPEC Fund for International Development
OPEC	Organization of Petroleum Exporting Countries
OPTS	Oil Producers Trade Section
PACP	Presidential Action Committee on Power
PHCN	Power Holding Company of Nigeria
PP	Philip Perron
PPI	Private Participation in Infrastructure
PTFP	Presidential Task Force on Power
PV	photovoltaic
R&D	Research and Development
RE	Renewable Energy
REEP	Renewable Energy and Energy Efficiency Programme
RETs	Renewable Energy Technologies
RGDP	Real GDP
RFQ	Request for Quotations
ROA	Real Option Analysis
SAP	structural adjustment program
SAPP	Substance Abuse Prevention Program
SDR	Social Discount Rate
SON	Standards Organisation of Nigeria
STT	Social Technical Transition
STPR	Social Time Preference Rate
Tcf	trillion cubic feet
TCN	Transmission Company of Nigeria
TFP	Total Factor Productivity

Tscf	Trillions of standard cubic feet
UNCTAD	United Nations Conference on Trade and Development
UNFCCC	UN Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organisation
VAR	Vector autoregression
VECM	Vector Error Correction Model
WDI	World Development Indicators
WACC	Weighted Cost of Capital
WEO	World Economic Outlook
WTI	West Texas Intermediate

List of Tables

Table 2.1: Refineries and installed capacities 16
Table 2.2: Fossil energy resources as at 2012 17
Table 2.3: Renewable energy resources 20
Table 2.4: Summary of 2005–2016 renewable energy capital projects 24
Table 2.5: Average energy efficiency trend of selected countries 34
Table 2.6: Summary of policy implementation of the energy sector reforms 38
Table 3.1: Chronology of methodology used in the energy–growth nexus literature 50
Table 3.2: Empirical literature review on energy–growth–environment nexus 57
Table 4.1a: Augmented Dickey-Fuller unit root tests 79
Table 4.1b: Phillips-Perron unit root tests 80
Table 4.2: Bai-Perron multiple breakpoint test 81
Table 4.3: ARDL bounds test 83
Table 4.4: Long-run model 85
Table 4.5: Parsimonious short-run error correction model (disaggregated model) 85
Table 4.6: Parsimonious short-run error correction model (aggregated model) 86
Table 4.7: Diagnostic statistics 87
Table 5.1: Augmented Dickey-Fuller and Phillips-Perron unit root tests 101
Table 5.2: ARDL bounds test 101
Table 5.3: Cointegratiion equation (long-run model) 102
Table 5.4: ARDL short-run model 104
Table 5.5: Diagnostic statistics 105
Table 6.1: Costs and benefits associated with renewable technologies 117
Table 6.2: Technical and economic features of selected energy technologies 121
Table 6.3: Total life cycle cost of technologies ($Kw/yr) 122
Table 6.4: EPA-defined greenhouse gas (GHG) direct emission profiles 123
Table 6.5: Total environmental cost/Kw/yr in US$ 123
Table 6.6: Total life cycle cost analysis of energy options (US$KW) 124
Table 6.7: Annual financial benefits (values in KWh/yr.US $) 125
Table 6.8: Estimation of benefits from energy technologies (values in $) 127
Table 6.9: Levelised cost of energy @ 60 USD/tCO_2e (base case) 128
Table 6.10: Comparative analysis of BCR and LEC in US$/KWh (base case) 129

Table 6.11: Analysis of energy supply (optimistic) @ 40 USD/tCO_2e and WACC 8% 130
Table 6.12: Analysis of energy supply (pessimistic) @ 100 USD/tCO_2e and WACC 15% 130
Table 6.13: Comparative scenario analysis of levelised costs 131
Table 6.14: Comparative scenario analysis of benefit costs ratio 131
Table 6.15: Primary energy consumption in Nigeria (2010) 134
Table 6.16: Nigerian total primary energy consumption (2013) 135
Table 6.17: Proposed energy consumption basket in Nigeria (2018) 136
Table 6.18: Proposed energy portfolio mix in Nigeria (2018) 136

List of Figures

Figure 1.1: Trend of GDP, fossil and renewable energy consumption (1990–2017) 3
Figure 1.2: Human Development Index and energy use per capita in 2012 4
Figure 2.1: Gas production and consumption in trillion cubic feet 18
Figure 2.2: Crude oil and other liquids production/consumption in million b/d 19
Figure 2.3: Proportion of various energy forms in total energy use (%) 25
Figure 2.4: Energy use by sector 26
Figure 2.5: Oil and total revenue in Nigeria (1999 to 2014) 27
Figure 2.6: Electricity consumption (per capita KWH) 30
Figure 2.7: Evolution of electricity access and targets for 2010 and 2030 (%) 31
Figure 2.8: Trend of energy intensity in Nigeria from 1981-2016 (Btu/$) 33
Figure 2.9: Energy intensity trend in selected countries from 1981–2017 (Btu $) 35
Figure 4.1: ADF breakpoint test (GDP) 82
Figure 4.2: ADF breakpoint test (FEC) 82
Figure 4.3: ADF breakpoint test REC 82
Figure 5.1: Stages of economic-environmental development relationship 97
Figure 5.2: Plot of the EKC turning points 103
Figure 6.1: Comparative analysis of LEC, BCR and tariff in (KW) @ $60/tCO_2e$ 132
Figure 6.2: Comparative analysis of LEC, BCR and tariffs in (KWh) @ $40/tCO_2e$ 132
Figure 6.3: Comparative analysis of LEC, BCR and tariffs in (KW) @ $100/tCO_2e$ 133
Figure A.1: Model selection (energy-growth nexus): disaggregated model 156
Figure A.2: Plot of actual and fitted residuals model for real output 156
Figure A.3: Stability test: CUSUM disaggregated model 157
Figure A.4: CUSUMsQ disaggregated model 157
Figure A.5: Model selection (energy-growth nexus) aggregated model 158
Figure A.6: Plot of actual and fitted residuals model for real output 158
Figure A.7: Model selection EKC model 159
Figure A.8: Plot of actual and fitted residuals model for real output 159
Figure A.9: Stability test: CUSUM 159

CHAPTER ONE
INTRODUCTION

1.1 Background of the study

The contribution of energy to economic growth in developed and developing countries has been a controversial topic in economic theory (Murillo-Zamorano, 2005). The theoretical and empirical literature on the impact of energy on economic growth are inconclusive. While most empirical studies have concentrated largely on finding the causal direction that exists between energy consumption and growth[1], studies on the disaggregated effects of energy consumption components (renewable and non-renewable) on economic growth have been rare. Although energy consumption contributes positively to economic growth, disaggregating energy components into renewable and non-renewable energy sources may render the link between energy and growth to be varied (Hisnanick and Kymn, 1992; Chien and Hu, 2007; Turner and Hunley, 2011; Tugcu, 2013).

The consumption of conventional energy based on oil, coal, and natural gas has proven to be an effective driver of economic growth, though evidence has also shown that such growth can have negative influence on the environment (Newman et al., 1996). In particular, concerns about global warming, climate change and increase in energy demand have renewed the desire for intense research on the effect of energy consumption on economic growth (Saddiqui, 2004; Apergis and Payne, 2010a; Apergis and Payne, 2010c). In this case, economic growth may present challenges to developing countries where growth is fuelled largely by fossil fuel such as crude oil, gas and coal. According to IPCC (2011) estimates, conventional energy is the dominant contributor to the greenhouse gas (GHG) concentrations that are the main causes of global warming. It is said to be accountable for more than 60 per cent of the greenhouse effect (Ozturk and Acaravci, 2010). This has therefore scaled the extensive research on the deployment of renewable energies.

While the clamour for renewable energy resources is centred on the premise that renewable energy helps to increase universal access to energy, especially in rural areas and in a sustainable manner (UNCTAD, 2010), the concern for alternative

[1] See Hamit-Haggar, 2012; Tugcu et al., 2012; Lee and Chang, 2007; Akinlo, 2008; Odhiambo, 2009; Payne, 2009; Ozturk et al., 2010; Ozturk and Acaravci, 2010); Tsani, 2010; Vaona, 2012; Gollagari and Rena, 2013; Chen, 1999; and Carter, 1974.

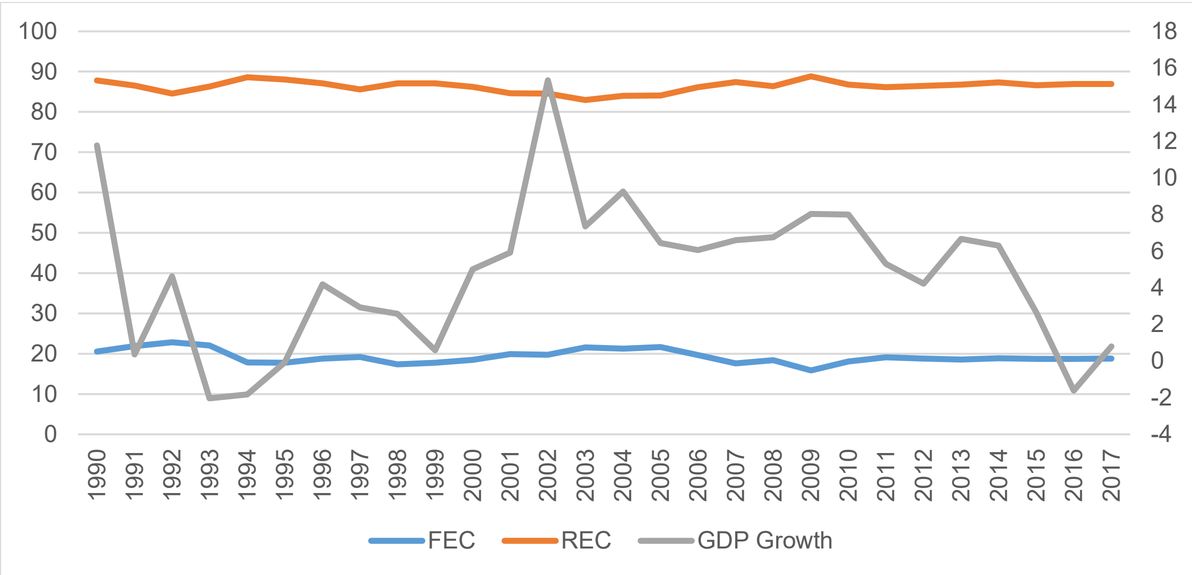
energy in the context of sustainable growth in developing countries (particularly in African countries) has generated much debate. In particular, the nature of the impact of energy consumption on economic growth, the process through which such effects evolve during economic development, and the implications for growth and poverty alleviation across countries are unclear. Some studies appear to cast doubt on the positive effects of renewable energy on growth, particularly in the context of developing countries which are well endowed in natural resources. Studies such as Resnick, Tarp and Thurlow (2012), Scott (2013), Dercon (2012), Dercon (2011) and Huberty et al. (2011) have carefully examined the internalisation of costs of environmental pollution which may affect the trend of growth and concludes that it is not very plausible that green growth will offer the rapid route out of poverty as it appears to promise. Therefore, the clear indication here is the need for more studies, especially on Africa.

Hence, achieving a sustainable economic growth which is largely driven by fossil fuel energy and its associated issue of deteriorating environmental quality presents huge developmental challenges. Africa is confronted with the crucial issues of producing more fossil fuels in meeting its current energy requirements and driving economic growth, while also faced with the issues of reducing greenhouse gas (GHG) emissions and meeting the demands of depletion of fossil fuel energy. These issues are forcing countries, largely those in the sub-Saharan Africa region, to redefine an energy strategy that departs from over-reliance on fossil fuels (Menyah and Wolde-Rufael, 2010).

Nigeria is one of such sub-Saharan African countries with these challenges. Energy supply is still dominated by conventional energy sources: petroleum, natural gas and coal. Although energy is viewed as one of the main drivers of economic growth, its contribution to GDP has declined from 15.5 per cent in 2012 to 13.7 per cent in 2013 (ECN, 2013). With a decrease in crude oil production, this could hamper economic growth if strategic policies are not put in place. This also poses an important developmental challenge for the country. Thus, the large energy deficit will have to be reduced if rapid growth and development is to take place. Interestingly, the country is endowed with substantial energy potential, in the form of hydropower, fossil fuel, solar and wind (Rapu et al., 2015). However, concerns over the ecosystem compel a re-definition of energy strategy that departs from over-reliance on fossil fuels. How these resources are harnessed will define the path of sustainable development in Nigeria.

Despite the substantial renewable energy potential, efforts by the government to change the energy structure (supply) to improve the energy sector have remained futile. Figure 1.1 presents the trend of GDP growth rate and the share of fossil and renewable energy consumption for the period 1990-2017. Over time, the share of renewable energy consumption has remained fairly high compared to the share of fossil energy consumption. The share of renewable energy consumption in total energy consumption is about 87.3 per cent in 2017, however, this does not mean that Nigeria has made progress in renewable energy development as the structure of renewable energy is dominated by biomass resources such as firewood, crop stalks, etc. The figure suggests that the evolution of the trend of GDP growth follows that of fossil fuel energy consumption.

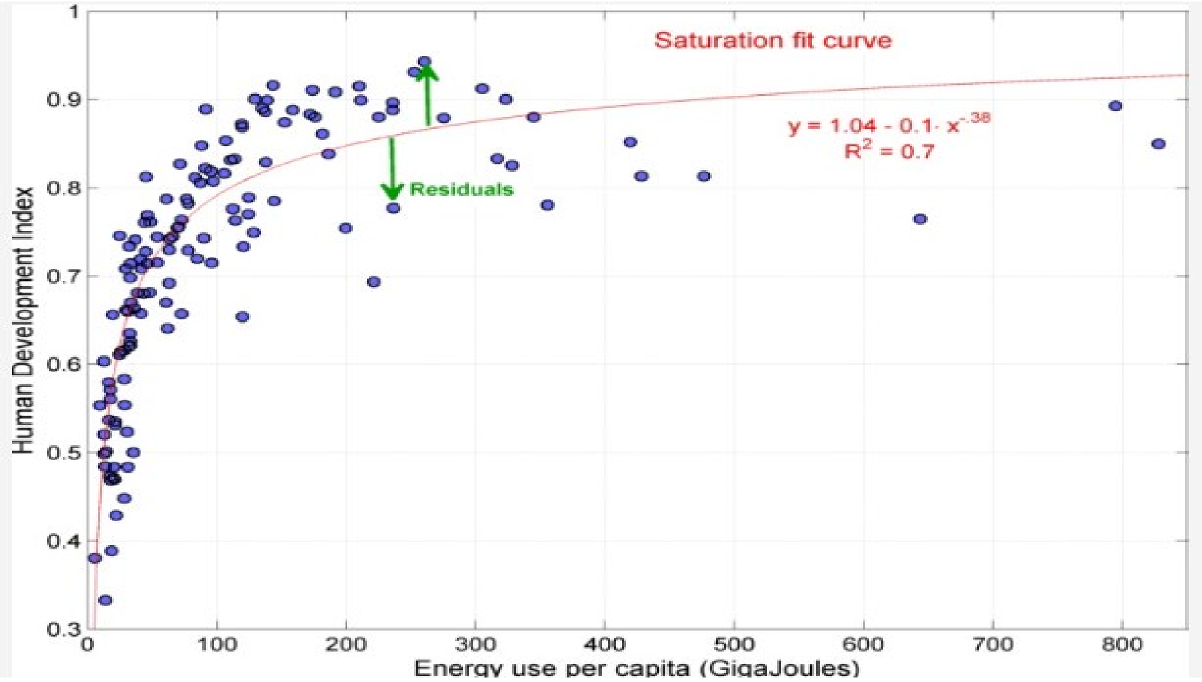
Figure 1.1: Trend of GDP, fossil and renewable energy consumption (1990–2017)



Source: World Bank Development Indicators

In achieving and sustaining economic growth and development, a constant supply of energy is required. Nigeria still battles with poverty and human development. Figure 1.2 relates energy consumption per capita to the level of human development. From the figure, it is obvious that a strong link exist between energy consumption and human development as shown by the upward sloping trend in the graph. Evidently, countries that grow over time, as most African countries do, do so in connection to improvements in energy consumption (Steinberger, 2016). According to the UNDP (2005), virtually few or no country in recent times has significantly attained a decrease in poverty without having to increase its energy consumption. Thus, achieving sustainable economic growth and development that will reduce poverty and improve human development requires substantial amounts of energy and yet energy access remains very low in the country.

Figure 1.2: Human Development Index and energy use per capita in 2012



Source: Steinberger (2016)

In view of this background, the study explores the effects of energy consumption on economic growth, the influence of economic growth on environmental quality, and also analyses the various energy options in Nigeria. The study is structured in three standalone essays.

1.2 Statement of research problem

Although energy consumption is viewed as a main driver of economic growth (Toman and Jemelkova, 2003; Schurr, 1983; Rosenberg, 1983; Jorgenson, 1983, 1984), the mainstream theory on economic development pays less attention to the important role of energy in the production process (Stern and Cleveland, 2004). Hence theoretical literature has been defective in explaining the influence of energy on growth. Although the mainstream growth theory has been extended by including an energy variable, the influence of energy on growth has been debated intensely by various economists (Ebohon, 1996).

For instance, while energy would engender economic growth, the negative effect of rapid economic growth on environmental quality due to the consumption of conventional energy has been questioned. Thus, even though energy consumption may be seen to impact growth, such growth may also be detrimental to the environment. This has implications for the Environmental Kuznets Curve (EKC) hypothesis that states that the link between per capita income and environmental quality is an inverted-U-shaped curve (Kuznets, 1955). Therefore, a number of studies have endeavoured to test the validity of the EKC, by studying the effect of economic growth on environmental quality in both developed and developing countries (Chang, 2014; Sulaiman et al., 2013; Tugcu et al., 2012; Wang et al., 2011; Menyah and Wolde-Rufael, 2010; Acaravci and Ozturk, 2010). These studies have however mostly yielded inconclusive results.

Similarly, empirical literature has focused mainly on the causal direction between energy consumption and economic growth (Hamit-Haggar, 2012; Tugcu et al., 2012; Lee and Chang, 2007; Akinlo, 2008; Odhiambo, 2009; Payne, 2009; Ozturk et al., 2010; Ozturk and Acaravci, 2010; Tsani, 2010; Apergis and Payne, 2010b; Vaona, 2012; Gollagari and Rena, 2013; Chen, 1999; Carter, 1974). But studies on the disaggregated effects of energy consumption components (renewable and non-renewable) on economic growth have been rare. Although positive contributions are expected from the consumption of energy on economic growth, disaggregating energy input into its components may cause these contributions to vary based on the energy source in consideration (Hisnanick and Kymn, 1992; Chien and Hu, 2007; Turner and Hunley, 2011; Tugcu, 2013). The combined and disaggregated growth effects of energy consumption on growth have policy implications as they provides a basis for discussing energy and environmental policies.

Due to the debilitating environmental impacts of conventional energy sources, there has been increased attention on the deployment of renewable energy. However, the technology for transiting to renewable energy is not yet certain and proven when considering the economic and financial costs. Hence it is highly debatable that transiting to renewable energy sources can in itself generate the growth that most countries, particularly developing countries, desire. This is because conventional energy to fuel growth may bring about a speedy route out of poverty (Resnick et al., 2012; Scott, 2013; Dercon, 2012; Huberty et al., 2011). This uncertainty and debate further exacerbates the energy-growth puzzle. One way of trying to understand this complexity is to decompose energy sources (conventional and renewable) and analyse the effect of the different energy sources. There are however few theoretical and empirical investigations in this direction.

The need for options in energy sources to improve energy supply is another major challenge in the choice of options for energy production. The costs and benefits of developing these options vary greatly and in some cases could be a toll on revenues and, more seriously, on the environment (Fankhauser and Jotzo, 2017; Polzin, 2017; Roche, Ude and Ofoegbu, 2017; GOPA-intec, 2017; Wang and Zhi, 2016; OECD, 2011). Equally challenging is the issue of financing, particularly for a developing country such as Nigeria. Therefore an empirical evaluation of the costs and benefits associated with the deployment of renewable energy sources is imperative for developing countries, especially Nigeria, where there are enormous primary energy resources.

While it has been argued that renewable energy is an option to enhance energy supply in Nigeria, its contribution to total energy sources is still minimal. Although there have been various explorations of renewable energy in Nigeria since the 1990s, conventional energy sources still dominate the energy mix. Although the share of renewable energy consumption in total energy consumption stood at about 87.3 per cent as at 2016, however, it consists largely of energy sources such as firewood and crop stalks and does not mean that Nigeria has made progress in renewable energy development. The excessive use of such energy sources, especially in rural areas, poses health and environmental challenges and underscores the need for urgent energy intervention.

In terms of the extent of renewable energy resources in electricity production, its share is only 18 per cent in 2016 compared to fossil fuel which contributes 82 per cent. The entire 18 per cent from renewables is mainly from hydroelectricity sources. Other renewable energy sources such as solar and wind are largely unexploited and only operate on a very small individual scale. Renewable energy sources are still perceived as a high-risk investment despite recent technological and policy innovations (Roche et al., 2017). However, empirical evidence shows that with appropriate policy support, renewable energy is competitive. Therefore, this study addresses the gap in the literature by examining the competitiveness of conventional and renewable energy sources in Nigeria and suggests alternative options to boost energy supply.

This thesis makes some important contributions to the energy-growth-environment literature. The bulk of the studies on energy-growth nexus are panel studies and do not reveal important country-specific dynamics. For instance, whilst energy issues cut across all countries, the growth effect differs across countries according to their stages of development. Although Nigeria is a large producer and exporter of primary energy resources, it has peculiar characteristics which makes it different from other energy-endowed countries. Nigeria has the largest population of Organization of the Petroleum Exporting Countries (OPEC) member countries at over 190 million, GDP at market price of $371,886 million, GDP per capita of $1,881, proven crude oil and natural gas reserves of 37,453 million barrels and 5,627 billion cubic metres respectively, oil demand of 425,900 barrels per day, and value of petroleum exports of $38,607 million (OPEC, 2018).

This contrasts sharply with other energy producing countries such as Saudi Arabia, which has a population of 32.5 million, which is less than one-fifth of Nigeria's population, GDP at market price of $683,827 million, GDP per capita of $21,007, proven crude oil and natural gas reserves of 266,260 million barrels and 8,715 billion cubic metres respectively, oil demand of 324,200 barrels per day, and value of petroleum exports of $159,742 million. Angola, a major energy producing country in sub-Saharan Africa, has a population of 28.3 million, GDP at market price of $124,209 million, GDP per capita of $4,380, proven crude oil and natural gas reserves of 8,384 million barrels and 422 billion cubic metres respectively, oil demand of 115,500 barrels per day, and value of petroleum exports of $31,550 million.

According to the World Development Indicator of the World Bank, Nigeria has an energy use per capita of 763.3 kg of oil equivalent (in 2014) and a poverty headcount ratio at $1.90 per day of 53.5% (in 2009) while Saudi Arabia has an energy use of 6,937 kg of oil equivalent (in 2014), and Angola has a poverty headcount ratio at $1.90 per day of 30.1% (in 2008). Given the wide disparity in energy and economic conditions even among energy producing countries as the narrative above shows, a single country analysis is more suitable to understanding Nigeria's energy sector and growth. Thus this study contributes to the literature by analysing the energy-growth linkages in a country endowed with substantial primary energy sources, but whose population has limited access to modern energy services.

In addition to enabling the understanding of the energy-growth nexus in an energy-endowed and exporting country, another unique contribution of this thesis is that it distinguishes between the growth linkages of renewable and non-renewable energy by decomposing energy components. Based on the premises that renewable energy consumption can pave the way for growth particularly for developing economies, a decomposed analysis of energy components was employed to evaluate the separate effects of energy components on growth. Since Nigeria faces large growth and development gaps despite the large deposits of renewable and conventional energy, the study further tests for the combined effect of renewable and non-renewable energy on economic growth by examining the growth effect of the interaction between renewable and conventional energy on growth. It shows that instead of the various alternative hypotheses around energy and growth, there may be a unique combination present for different countries.

The study also contributes to the literature on the EKC hypothesis. While there are several studies that have investigated the validity or otherwise of the EKC, including for Nigeria, there are no known studies that have estimated the turning point of the EKC for the Nigerian economy. Given the energy-dependent nature of the Nigerian economy, it is important for policy makers to understand the point at which the economy will transition from a pollution-intensive economic growth path (the increasing stage of the EKC) to a green growth path (the decreasing stage). This thesis therefore further contributes to this discussion as different countries have different turning points depending on the structure of the economy, energy consumption mix and other factors. Specifically, it not only determines the validity or otherwise of the hypothesis as most Nigerian-focused studies have done, but it is the first known study to attempt to estimate the turning point of the EKC for the Nigerian economy.

Lastly, the study examines the optimal mix for energy access in Nigeria by analysing the cost and benefit of alternative energy sources in Nigeria. While Nigeria is endowed with substantial renewable and non-renewable energy resources, there have been limited scientific efforts to determine the relative viability of these energy sources with a view to determining the optimal mix that can support the attainment of the country's energy access goals. Several studies have been conducted on the viability of alternative energy sources (Lai and Mcculloch, 2017; IRENA, 2018; Shrimali et al. 2016; Kost et al., 2018), but the levelised costs of different energy sources vary across countries due to differences in energy potential, technical know-how, socio-economic conditions, and government policies.

Attempts to analyse the viability of alternative energy sources in Nigeria have been limited to very few studies (Roche, Ude and Danald-Ofoegbu, 2017), due partly to the lack of data on the technical aspects of the various energy sources. This thesis therefore builds on Roche et al. (2017) and contributes to the literature by analysing the viability of alternative energy sources options in Nigeria using levelised cost of electricity, life cycle cost analysis and cost-benefit ratio. This study accounts for externalities by incorporating the environmental costs/benefits of each energy source. The findings of the study will be important for determining the energy portfolio mix for Nigeria and serve as a guide for enhancing energy access in the long term.

1.3 The case for Nigeria

This study therefore focuses on a single country – Nigeria – for analysis. Nigeria is chosen for several reasons: (1) despite the huge abundance of renewable and conventional energy resources, there exist huge energy deficits (Rapu et al., 2015), and the economy has not been able to attain sustainable growth. Besides, despite Nigeria sharing energy-endowed and dependent status with several other countries, the economic conditions and energy sector differ considerably, as shown above, the energy sector and economy of Nigeria and other energy-producing countries such as Saudi Arabia and Angola vary substantially. So it is important to understand the effects of energy alternatives (renewable and non-renewable) on economic growth in Nigeria bearing in mind the peculiarity of the energy sector and economy of the country. (2) Nigeria has committed to several environmental goals and policies such as the landmark 2015 Paris Climate Agreement. Understanding the threshold effect of energy, growth and environment has policy implications for the attainment of these development and environmental goals. (3) Nigeria is largely dependent on fossil fuels for growth. However, the need to narrow the energy deficit gap and commitment to environmental protection policies have necessitated the deployment of alternative energy sources. Understanding the effects of energy use on growth and ultimately on the environment as well as the identification of viable energy options (renewable and non-renewable) for an optimal portfolio mix are important for policy makers in Nigeria.

1.4 Research objectives of the study

The broader objective of the study is to examine alternative energy options, economic growth and the environment in Nigeria. The specific goals of the study are:

1. To establish the effects of energy consumption (conventional and renewable) on economic growth;
2. To evaluate the impact of economic growth on the environment; and
3. To analyse the economic viability of the different energy options.

1.5 Research questions

The study intends to provide answers to the questions below:

1. Does disaggregated energy consumption have a differential effect on economic growth in Nigeria?
2. Does economic growth influence environmental quality?
3. How economically viable are the different energy options in Nigeria?

The study is structured in three stand-alone essays on (1) the effects of energy consumption on economic growth, (2) the impact of economic growth on the environment, and (3) the economic viability of alternative energy options for optimal energy mix in Nigeria.

1.6 Rationale for each essay and significance of the study

This study follows three stand-alone papers structured within the range of this dissertation.

The first paper investigates the combined and disaggregated effects of alternative energy consumption on growth in Nigeria. Theoretically, energy is critical for both economic and social development. However, the empirical literature has focused mainly on the direction of causality between energy consumption and economic growth (Cowan et al., 2014; Soytas and Sari, 2003). But research on the impacts of disaggregated energy consumption (renewable and fossil) on economic growth, which may vary based on the energy sources in consideration, have been rare. Therefore, it has been argued that disaggregating energy input into its components may counter the difference in results depending on the energy sources in consideration.

The limited empirical studies in this regard create a gap in the literature, which is compounded by the environmental effect of energy consumption. This paper, unlike other studies, considered the decomposed and joint effects of renewable and conventional energy on economic growth, which constitutes an important gap that this study filled. Therefore, this paper employed annual time series data, and an Autoregressive Distributed Lag (ARDL)-bounds testing approach by Pesaran et al. (2001) to explore the effects of renewable and conventional energy consumption on economic growth in Nigeria. Thus the study offers further insights into the literature and context.

The second paper builds on the first one. Given the potential effects of energy consumption on economic growth as analysed in the first objective, it is also essential to investigate how such growth will affect the environment. This is the second objective and main focus of the second paper in the thesis. The paper examines the effect of progressive growth on the environment. Although growth has been argued to cause environmental degradation due to the consumption of fossil fuels, the EKC hypothesis states that pollution will first increase with income and then later decrease at higher levels of income. However, empirical findings on the validity of the EKC have been mixed and vary across countries and context. This constitutes a gap in the literature, particularly in the context of the Nigerian economy. Besides, there is no known study that has attempted to estimate the turning point of the EKC for the Nigerian economy. Therefore, this paper studied the validity of the EKC hypothesis in the Nigerian context, by exploring the interaction between economic growth, energy consumption and the environment using ARDL. It also estimates the threshold point of the EKC for Nigeria. The study will enhance the understanding of the possibility of simultaneously attaining economic growth and environmental protection in Nigeria.

Following the effects of energy consumption on economic growth (objective one), and the environmental consequences of energy-induced growth (objective two), it is important to analyse the viable options to improve energy access while minimising the environmental impacts. This is the main goal of the third paper. The third paper evaluated the economic viability of alternative energy sources for an optimal portfolio mix in Nigeria. The case for renewable energy is centred on the premise that renewable energy helps to expand universal access to energy, especially in rural communities in a sustainable manner (UNCTAD, 2010). However, the literature for transiting to renewable energy, particularly in developing countries, is not yet clear. Nonetheless, the extent to which renewable energy can enhance energy access in Nigeria has not been adequately exploited. The paucity of studies in this area constitutes a gap which this study filled. This paper therefore employed a cost benefit analysis to analyse the economic viability of alternative energy options for optimal energy mix in Nigeria.

1.7 Methodology

This thesis employs the Autoregressive Distributed Lag (ARDL) model for the first and second objectives while cost-benefit analysis is used for the third objective. To test for the existence of short- and long-run relationships between variables, two methods (Engle and Granger, 1987; Johansen and Juselius, 1990) are commonly used. However, these methods can be applied only when the variables are integrated of the same order, which is usually a strict requirement. This implies that the order of integration of the variables needs to be first determined. Besides, according to Banerjee et al. (1986), estimation of the static model by OLS can lead to bias in finite samples as a result of omitted short-run dynamics. This makes the OLS estimator for the long-run parameters to be non-normal, undermining a basic assumption of the estimator.

To overcome the limitations of the traditional methods, the ARDL model was developed by Pesaran et al. (2001). This method improved on the Engle-Granger and Johansen-Juselius cointegration methods by testing for the existence of a long-run relationship between variables without demanding the variables to be integrated of the same order. In the ARDL model, the underlying variables can be I(0) or I(1) or a mixture of both. The test draws conclusive inference without prior knowledge of whether the variables are I(0) or I(1) (Pesaran et al., 2001). According to Pesaran and Shin (2008), the OLS estimators of the short run parameters are normally distributed and consistent while the long-run parameters estimators are normally distributed regardless of the order of integration and super-consistent if the regressors are I(1). Pesaran et al. (2001) also provide the asymptotic critical values that range from when all the regressors are I(0) to when they are all I(1).

In addition, the econometrics literature has shown that that the ARDL is the most appropriate cointegration model and relatively more efficient than the traditional cointegration techniques when dealing with small or finite sample data sizes (Narayan, 2005; Nkoro and Uko, 2016). Narayan (2005) computes the corresponding critical values for small sample sizes. This is a critical factor in the choice of the method for this study considering the number of observations in this study (1980-2016). Furthermore, an appropriate modification of the order of the ARDL technique can correct and provide unprejudiced estimates of the long-run model and valid t-statistics even when some of the regressors are endogenous. These advantages of the ARDL have made it the most current and widely used method in the literature. Several studies such as Akinlo (2008), Odhiambo (2009), Ozturk and Acaravci (2010), Wang et al. (2011), Zhao et al. (2016) and Gozgor (2018) have employed this method for analysis, and hence its adoption for the first and second objectives of the thesis.

To confirm the validity and reliability of the ARDL method used in the thesis, several diagnostic/robustness tests have been conducted. These tests include the CUSUM and CUSUM-squared test, Breusch-Godfrey LM and Durbin-Watson tests for serial correlation, ARCH and Breusch-Pagan tests for heteroscedasticity, and Jarque–Bera test for normality.

For the third empirical paper, the cost-benefit analysis is employed. This is based on the life cycle cost analysis, levelised cost of energy and benefit-cost ratio. These methods calculate the cost of an energy source option and compare the life cycle (unit) cost with those of other energy options. This is the most standard methodology applied in this area and has been used by several studies in different country contexts (see IRENA, 2018; Shrimali et al. 2016).

1.8 Contribution of the study

The study makes a unique contribution to the literature in three main ways. First, it is one of the first few studies to explore separately the effect of alternative (renewable and conventional) energy sources on the economy in Nigeria. This approach presents clarity in the literature on the varied growth effects of disaggregated energy sources and its usefulness for developing countries transiting the energy growth path. The study showed that for a developing and (renewable and conventional) energy-endowed country such as Nigeria, the path to increased growth and rapid development cannot be by renewable energy alone, rather a more careful approach of combined energy sources (renewable and non-renewable) would be necessary to achieve growth.

It is recognised in the literature that energy is essential for economic growth and the relationship between them is situated in the four main hypotheses (growth hypothesis, conservation hypothesis, neutral hypothesis and feedback hypothesis) which are built on aggregate energy consumption. Fossil energy consumption is beneficial for economic growth, but has been identified as the major cause of anthropogenic (man-made) climate change. Contrary to the existing literature which is built around aggregate energy consumption, conventional and alternative energy sources could exert different effects on economic growth. This understanding is important for policy makers in focusing on a comprehensive examination of an optimal energy portfolio to drive sustainable economic growth and development while also ensuring environmental sustainability.

Secondly, the study also adds to the literature by computing the threshold effect in the EKC hypothesis using Nigeria as a case. The theoretical underpinning of the EKC is based on the postulation that increasing income in developing countries would lead to more consumption of goods and services, whose value chains are environmentally intensive. Also, during the early stages of economic growth, countries would invest in growth-inducing activities such as infrastructure investment and energy consumption which will increase environmental footprints. During this stage, economic growth is the major development goal. This pattern will continue till a certain level of economic growth and development is achieved (threshold point) after which higher income levels will be associated with declining environmental pollution or better environmental quality. At this point, the country would have achieved higher economic growth and resources to invest in an environmentally friendly economic model. China's economic development follows this pattern. Also, at this point, people's basic needs have been met and they begin to demand a cleaner environment.

Although the literature discusses at length the possibility and validity of this hypothesis and its extensions, very few studies exist on the exact threshold where the effect of growth on the environment changes, particularly in Nigeria. By incorporating nonlinear terms, this study shows the turning point (threshold) of the link between economic activity and the quality of the environment and confirms the shape of the relationship to support the EKC hypothesis for Nigeria. This helps in rethinking policy strategies that will enhance growth and improve environmental quality at the same time.

Third, the study also makes a unique contribution of providing a pathway to identifying optimal energy portfolio in the literature. Although energy use comes from diverse sources and countries use combinations of different sources to provide energy, there is no clear pathway in the literature to come up with optimal energy portfolio choices. Given the different costs and benefits of several energy sources and the context of different energy endowments across countries, it is important to have a theoretically sound means of creating or proposing an optimal energy mix that is supportive of economic growth.

Generally, using conventional energy sources to drive economic growth is relatively less costly than alternative energy sources. However, given the high environmental costs of conventional energy, creating a space for alternative energy sources becomes imperative. The cost disparities between the two energy sources make it important to determine an optimal mix in a way that sustains economic growth. Using a discounted cost-benefit analysis, life cycle cost analysis, levelised cost analysis and supply potential of multiple energy sources, this paper determines the viability of different energy options for Nigeria and proposes a portfolio of options which the country can consider in her energy production and use.

1.9 Outline of the thesis

The thesis is organised around three main themes similar to the research questions and objectives. Each theme has been developed into a stand-alone essay. In terms of chapters, the thesis consists of seven chapters. The first chapter introduces the research by highlighting the research problem, objectives and the significance of the study.

Chapter Two provides a contextual background on the history and development of energy starting from the period when oil and gas was discovered in Nigeria, and Chapter Three discusses the theoretical linkages of the energy-growth-environment nexus. Chapter Four is the first standalone essay and is an empirical study on the effects of combined and disaggregated energy consumption on economic growth. Chapter Five is the second standalone essay on the influence of economic growth on the environment within the framework of the EKC hypothesis. Chapter Six is the third standalone essay on the economic viability of alternative energy options for optimal energy mix in Nigeria. The thesis ends with Chapter Seven which provides the conclusion and policy recommendations.

CHAPTER TWO
ENERGY SECTOR DEVELOPMENT IN NIGERIA
STYLISED FACTS AND OVERVIEW

2.1 Introduction

This chapter discusses the history and development of the Nigerian energy sector. It highlights the composition and the importance of energy to the economy, the various energy options and endowments, pricing and volume trends, climate and environmental issues, policy evolution, financing options and constraints.

2.2 Historical development of the Nigerian energy sector

The Nigerian energy sector became formalised by 1914 when the Minerals Oil Ordinances of Nigeria was completed by the colonial masters. Prior to the discovery of oil in the late 1950s, the economy's major power source was coal, representing almost 70 per cent of the nation's total primary energy consumption. After oil was discovered, Nigeria became a member of OPEC in 1971. Thereafter the economy became solely dependent on crude oil reserves with very little focus on other energy sources (ECN, 2013).

At independence in 1960, generation capacity increased a little above 50MW of distributed power generation, when the population of the country was 43 million. Over the years, the government retained and managed the only existing four oil refineries in the country with total installed capacity of 445,000 bpd. However, from 1989 to date there has been no addition of new refineries to meet the increasing energy demand for a population of about 193 million, growing at an average of about 3.2 per cent annually. Over time, the capacity utilisation of these refineries has decreased to undesirable levels without adequate maintenance (see Table 2.1). According to ECN (2014), the average refining capacity utilisation in 2012 was 21 per cent, leading to increasing reliance on the importation of refined products to meet domestic need.

Table 2.1: Refineries and installed capacities

Refinery	Year com-missioned	Capacity (Barrels/day)								
		1965	1971	1978	1980	1987	1988	1989	1998	2014
P/H Refinery 1	1965	35,000	60,000	60,000	60,000	60,000	60,000	60,000	60,000	60,000
P/H Refinery 11	1989	-	-	-	-	-	-	150,000	150,000	150,000
Warri Refinery	1978	-	-	100,000	100,000	125,000	125,000	125,000	125,000	125,000
Kaduna Refiner	1980	-	-	-	110,000	110,000	110,000	110,000	110,000	110,000

Total		**35,000**	**60,000**	**160,000**	**270,000**	**295,000**	**295,000**	**445,000**	**445,000**	**445,000**

Source: ECN (2014)

Evidently, the energy sector in Nigeria has experienced fundamental changes in recent times. These changes started with the deregulation of the diesel market in 2009, which was followed by the partial removal of fuel subsidy in 2012, and the denationalisation of the power sector in 2013 (Anyaka, 2014). In addition, the Federal Government signed the memorandum of understanding (MoU) with a consortium of the European Union, the United States Government and the German Government in 2015 as part of the steps taken to sustain skills development in the sector (Anwana and Akpan, 2016).

2.3 Energy sources and reserves

Since the discovery of oil in 1956, Nigeria has remained one of the top producers of oil in Africa. The country is also well endowed with other primary energy resources, including fossil fuel and renewable energy resources. The country's reserves of energy resources are currently estimated as shown in Table 2.2. Till date, crude oil and gas remain the mainstay of the economy, generating roughly $87 billion worth of revenue in 2014, which represented almost 58 per cent of total government revenue in 2014 (IMF, 2014). Over the years, revenues generated from oil and natural gas has remained a major contributor to foreign earnings and accounts for almost 95 per cent of total exports to the world in 2014 (EIA, 2016).

Table 2.2: Fossil energy resources as at 2012

Items	Resources	Reserves	Production (2012)	Domestic utilisation (2012)
1	Crude oil barrels	37.2 billion barrels	0.853 billion	0.164 billion barrels
2	Natural gas	187 Tscf	2.58 Tscf	77% utilised 23% flared
3	Coal	2.7 billion tonnes	0	Negligible
4	Tar sands	31 billion barrels of oil equivalent	0	0.224 million tonnes
5	Nuclear	Yet to be quantified	0	30kW experimental nuclear reactor

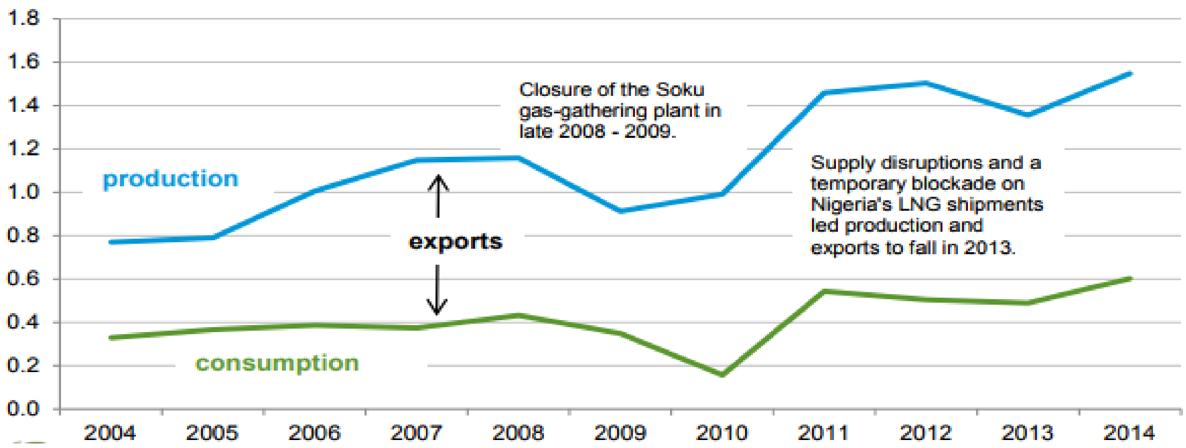
Source: ECN (2014)

2.3.1 Natural gas

Based on EIA estimates, Nigeria has one of the largest proven gas reserves of almost 187 trillion cubic feet (Tcf) as at the end of 2015 (EIA, 2016). However, till date the production of natural gas is constrained by lack of well-developed infrastructure and gas flaring. Although there has been a decrease in gas flaring from 540 billion cubic feet (Bcf) in 2010 to 379 Bcf in 2014, one of the continuous obstructions that has contributed to gas flaring has been the security issues in the oil-producing region of Niger Delta and the lack of sufficient partner funding that has decelerated headway on projects to apprehend associated gas. Another challenge that has also affected gas production is the lack of an appropriate regulatory framework.

Figure 2.1 presents the trend of gas production and consumption from 2006 to 2014. The figure shows an increased trend in the production of gas from 2005 to 2007. Disruptions in gas supply led to a fall in gas consumption in late 2008 and 2009. This was due to the shutdown of the Soku plant towards the end of 2008, which provided some considerable amount of feed gas to Nigeria's only LNG facility. In 2010, the country witnessed a stable increase in gas supply until 2013 when gas production declined by 10% to 1.35 Tcf due mainly to disruptions and a momentary blockade on Nigeria's LNG consignments. This resulted in a fall in exports and, to a much lesser degree, a fall in local consumption, because much of the gas produced isconsumed locally. Interestingly, Nigeria's natural gas production started to witness upward growth from 2011 to 2014, which recorded its highest level of 1.55 Tcf. Overall, Nigeria consumed 602 Bcf of dry natural gas in 2014, almost 40 per cent of its gas production (EIA, 2015).

Figure 2.1: Gas production and consumption in trillion cubic feet



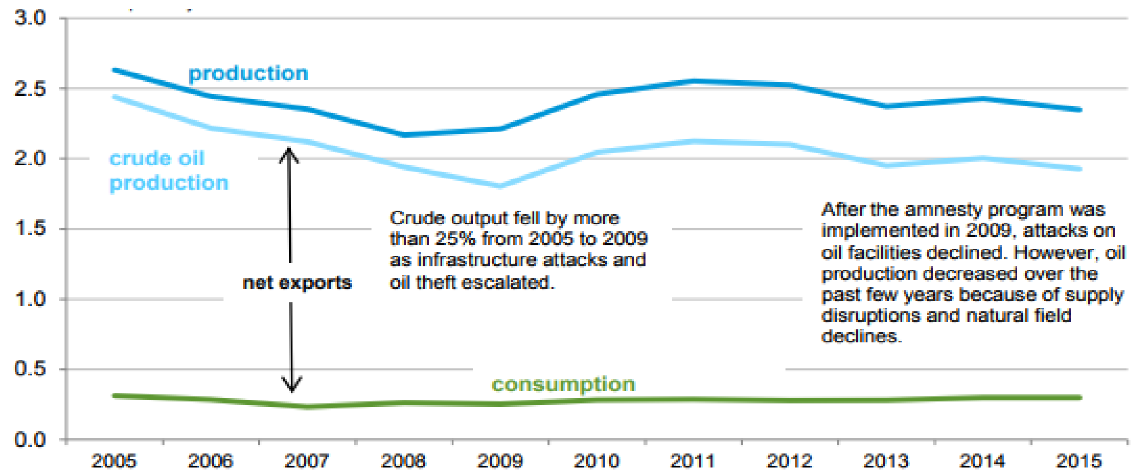
Source: EIA (2015)

2.3.2 Crude oil

According to ECN (2014), oil was discovered in large quantities in Nigeria in 1956 while production began in 1958. Nigeria had nearly a projection of 37 billion barrels of proven oil reserves at the end of 2015, making it one of the top producers in Africa (EIA, 2016). Evidence shows that the yearly oil production in Nigeria peaked to about 845 million barrels in 1979, though a decline in production to 451 million barrels was experienced in 1983 after a major market collapse that started in 1981 and lasted until 1987. However, records showed that the country witnessed an increase up to 776 million barrels in 1998. A glance at Figure 2.2 revealed that crude oil production peaked at 2.44 million barrels per day (b/d) in 2005, but that this was followed by a drastic decline just afterwards as militant violence surged, which led to many companies withdrawing their staff as well as the shutdown of oil production (CBN, 2016).

Lack of transparency in oil revenue management, pressures over the distribution of revenues, issues of environmental pollution from oil spills, and local ethnic and religious pressures led to the tense situations in the Niger Delta. As at the end of 2009, crude oil production plunged by more than 25 per cent to an average of 1.8 million b/d, but this fall was followed by an immediate increase as the government reached an arrangement with the Niger Delta militants which led to the inauguration of an amnesty programme. This continued till 2015, when Nigeria produced about 2.3 million b/d worth of crude oil and other liquids. Of this total, 1.9 million b/d was crude oil while the remainder was condensate gas plant liquids, and refinery processing increases (EIA, 2017).

Figure 2.2: Crude oil and other liquids production/consumption in million b/d



Source: EIA (2015)

2.3.3 Other fossil energy sources

There are other sources of energy in Nigeria such as tar sand, coal, nuclear, etc. However, these have not been utilised since the discovery of crude oil in the 1960s. Statistics have shown the existence of coal of sub-bituminous grade in almost 22 coal fields in 13 states of the Federation. Over the years, proven coal reserves run into 639 million tonnes while the inferred reserves are about 2.75 billion tonnes, comprising roughly 49% sub-bituminous, 39% bituminous and 12% lignitic coals (ECN, 2015). There is also a reserve of roughly 30 billion barrels of oil equivalent of tar sand. However, some of these resources have been neglected and have not been fully explored and developed.

2.3.4 Renewable energy sources

Renewable or infinite energy resources are sources of power that are derived from different sources that quickly replenish or regenerate in a fairly short period of time, usually through a natural process (ECN, 2012). In Nigeria, there is a vast renewable energy (RE) resource base which includes solar, wind, hydropower, biomass and other RE sources (tidal, ocean wave, geothermal, etc.) (ECN, 2014). Table 2.3 shows the reserves and utilisation levels of RE resources in Nigeria.

Table 2.3: Renewable energy resources

Items	Resources		Reserves	Utilisation Level
1	Large hydropower		11,250MW	1,900MW
2	Small hydropower		3,500MW	64.2MW
3	Solar energy		4.0 kWh/m2/day 6.5kWh/m2/day	15MW solar PV stand-alone No solar thermal electricity
4	Wind		2-4m/s at 10m height	2x2.5KW electricity generator; 10MW wind farm in Katsina
5	Bio	Fuel wood	11 million hectares of forest and woodlands	43.4 million tonnes of firewood/year
		Municipal waste	18.3 million tonnes in 2005* and about 30 million tonnes/yr now	-
		Animal waste	243 million assorted animals in 2001	-
		Energy crops and agricultural waste	28.2 million hectares of arable land	8.5% cultivated

Source: ECN (2014)

2.3.5 Solar energy

Solar energy is transmitted to the earth via radiation. The energy reaching the top of the earth's atmosphere is estimated at 1,400 watts/m^2. According to ECN (2014), solar energy is mostly well circulated all over the country if adequately harnessed, with an average total varying from about 12.6 MJ/m^2/d in the coastal latitude to about 25.2 MJ/m^2/d in the North. For instance, electricity production of about 207,000 GWh per year could be generated if only 1 per cent of the total land area (e.g. 920 km^2 = 920*106 m^2) were roofed with state-of-the-art poly-crystalline PV modules. This is almost the amount of total electricity generated in 2011 in the country and can be compared to the very high-yield sites in southern Spain, northern Africa, Australia and Latin America. Unlike the northern part of Nigeria, the south of Nigeria has less potential for solar energy as it is mostly associated with a longer rainy season. Thus, the economic viability and feasibility of solar PV in Nigeria is beyond question.

2.3.6 Hydropower energy

According to the Ministry of Power of Nigeria, hydropower is classified according to the generating capacity. Generating capacity of less than 1 MW is classified as mini, less than 30 MW as small, larger than 30 MW as medium and larger than 100 MW as large (FMWPH, 2015). Hydropower is one of the largest sources of renewable energy for electricity generation globally. It uses large and fast flowing water from high points which is converted into electricity. Despite the huge advantage of this renewable energy, Nigeria currently has about 1.9 GW hydropower capacity installed in three large power plants: Kainji 760 MW, Jebba 570 MW, and Shiroro 600 MW. Unfortunately, only about half of the capacity installed in the country is operational.

According to a World Bank report on the Federal Government of Nigeria (FGN) plans and feedback from stakeholders, there are high possibilities of increasing hydropower utilisation to 7.2 GW by 2035 (World Bank, 2013). However, use of hydropower must be considered carefully as the use of hydro means the diversion of water into mega-dams and this reduces natural flows, hampering access to human populations and animals that depend on rivers. In addition, a study by GIZ (2015) mentioned that hydropower potential may have been overrated in the case of Nigeria and that it could actually be more limited, due to the large seasonal differences.

2.3.7 Wind energy

Wind power refers to the natural occurrence associated with movement from airflow which is used to run wind turbines. Recent wind turbines range from about 600 kW to 5 MW of rated power, but turbines with a rated output of 1.5–3 MW are the most commonly used for commercial purposes. In most cases, the energy power obtainable from the wind is mostly due to the cube of the wind speed, so that as wind speed surges higher, the power output becomes higher to a point where the maximum output for specific turbines are stronger and more constant. Offshore and elevated sites are preferred locations for wind turbines.

In Nigeria, the annual average wind speed at 10m height varies from around 2m/s in the southern regions (places around the seaside) to roughly 4m/s in the northern region. When the speed reaches 50m, the range is 2m/s to 8m/s (ECN, 2015). In a recent wind mapping study by the Ministry of Science and Technology of Nigeria, the results indicated wind speeds of about 5m/s in the most appropriate locations. This shows that there is only moderate and confined potential for wind energy in Nigeria (Lahmeyer, 2005). So far, the highest wind speeds are experienced in the Northern regions of Sokoto, Jos Plateau, Kano, Funtua and Gembu. Stations in Maiduguri, Enugu and Lagos experience relatively fair wind speeds necessary for energy generation from wind farms.

There are other promising regions with operational wind potential located in the western shoreline (Lagos region) and partially on the Mambilla Plateau. Research has shown that the highest energy yields are at the coastal area of Lagos, followed by the Sokoto area and the Jos Plateau. Despite this huge potential, there are only two ongoing large wind farm projects: one in Katsina (10 MW), and one in Plateau State (100 MW).

2.3.8 Biomass

Biomass is associated with biological materials derived from plants. In Nigeria, biomass resources have existed for a very long time in various forms and in large quantities. These include agricultural crops, agricultural crop residues, municipal solid waste (MSW), forestry resources and animal waste. Over 60 per cent of Nigeria's population, particularly in rural communities, depends on biomass for energy use. A different source of biomass is MSW. This comes from households, commercial and industrial sectors due to the concentrations of population, and is gathered from the vast landfill dumps. The gas produced by natural decay from MSW at landfill sites (approximately 50% methane and 50% carbon dioxide) is collected from the stored material and polished and cleaned before it is fed into internal combustion engines or gas turbines to produce heat and electricity (ECN, 2015).

Unlike other energy sources, biomass is mostly used directly through combustion to generate heat, or indirectly after transforming it to other forms of biofuels. The conversion process from biomass into biofuel is achieved through different means which are broadly grouped into thermal, chemical, and biochemical systems. In general, wood remains one of the most common and largest sources of biomass, particularly in developing countries.

According to Ogwueleke (2009), roughly 25 million tonnes of municipal solid wastes are produced annually in Nigeria. Although Nigeria has available land and a wide range of biomass resources which can be used to produce biofuels and make her an international supplier, the process of burning biofuels and biogas to produce heat/electricity could result in environmental damage (ECN, 2014).

Energy constraints have limited economic activities for decades. Based on the review of energy resources, it can be ascertain that the deployment of alternative energy sources not only have the potential to grow the economy through the deepening of the real sectors but also to place the economy on the global scene (ECN, 2015). Therefore a more adequate, reliable, affordable and clean energy supply will not only improve the modernisation of agricultural activities but will also sustain the increasing value of life. In the long run, this will lead to job creation, increase productive activities and business development, and improve social service delivery and the overall development of the economy.

Based on this, the government has made efforts to expand energy supply to its citizens. One of the earlier steps by the government was the presidential directive to the Nigerian National Petroleum Corporation (NNPC) in 2005 to explore more renewable energy sources. A recent 2018 Bill passed by the Nigerian Parliament also mandated the Energy Commission of Nigeria (ECN) to prioritise renewable energy investments in the country. This was done in partial fulfilment of the dictates of the Kyoto protocol to which Nigeria is a signatory as well as a step towards the expansion of energy supply in the country.

The Nigerian Electricity Regulatory Commission (NERC) with other relevant stakeholders made a commitment to stimulate investments in the various energy options. A target to generate a minimum of 2,000MW of electricity from renewables yearly by 2020 was set. To achieve this, the NERC approved three windows for grid connected RE projects. Table 2.4 shows a summary of all RE projects since the establishment of the draft Renewable Energy Master Plan (2005).

Table 2.4: Summary of 2005–2016 renewable energy capital projects

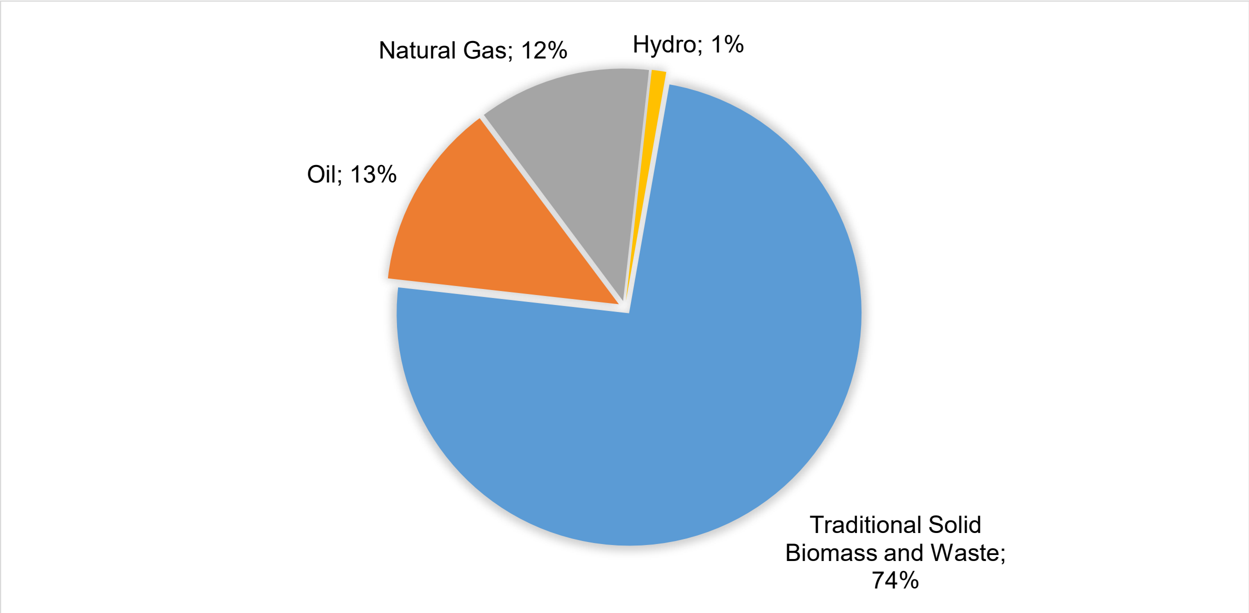
Year	Wind		Solar PV Streetlight		Solar PV Mini Grid		Solar PV Water Pumping		Total
	QTY	MW	QTY	MW	QTY	MW	QTY	MW	MW
2005	-	-	-	-	1	0.005	1	0.0011	0.006
2006	-	-	-	-	4	0.02	2	0.0005	0.021
2007	3	0.0075	-	-	1	0.005	-	-	0.012
2008	-	0.03	1,200	0.096	-	-	5	0.006	0.132
2009	-	0.03	18,541	2.318	-	-	98	0.117	2.465
2010	-	-	25,611	4.098	5	0.068	296	0.375	4.545
2011	-	0.002	5,100	0.816	1	0.04	72	0.086	0.944
2012	-	-	7,000	1.1	9	0.061	246	0.295	1.456
2013	-	-	7,522	1.204	4	0.016	88	0.106	1.326
2014	-	-	3,010	0.566	2	0.018	39	0.0468	0.631
2015	-	-	2,959	0.592	2	0.02	41	0.0492	0.661
2016	-	-	1,815	0.363	10	0.042	85	0.1020	0.507
Total	3	0.0695	66,458	11.151	39	0.295	973	1.1846	12.706

Source: ECN (2016)

2.4 Energy structure and sectoral consumption in Nigeria

According to EIA (2015) estimates, primary energy use in Nigeria in 2013 was about 4.8 quadrillion British thermal units (Btus). As shown in Figure 2.3, biomass and waste include charcoal, wood, crop residues and manure, representing a larger portion of about 74% of the total energy supply. This represents mainly the use of biomass in most homes to meet off-grid heating and cooking needs. Evidently, information on the use of biomass is imprecise due mainly to the fact that biomass sources are not easily traded in observable commercial markets. Despite the vast potential of conventional and renewable energy resources, these resources have not been adequately harnessed to bring about the desired economic growth (ECN, 2013).

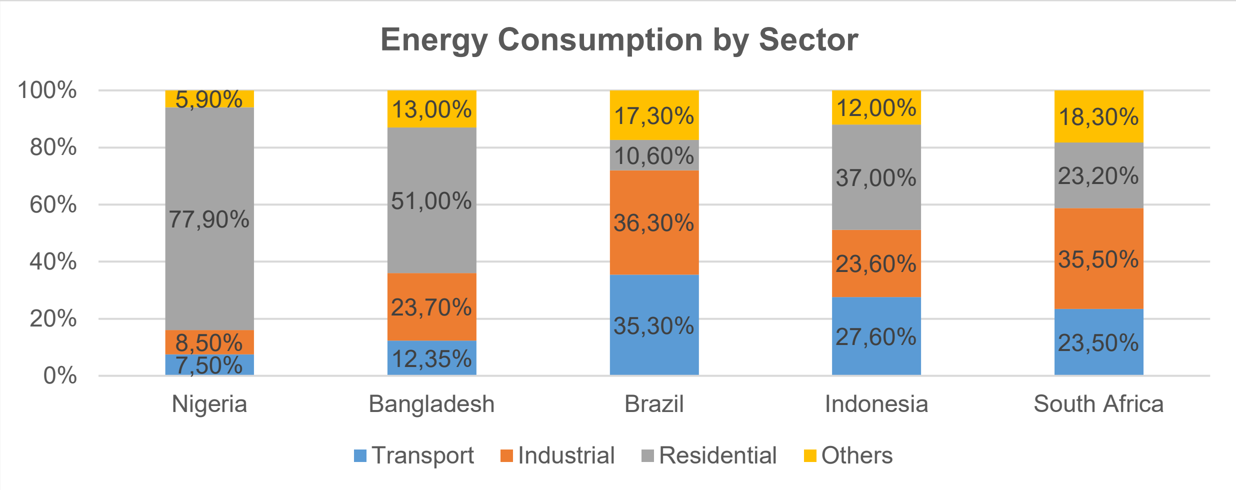
Figure 2.3: Proportion of various energy forms in total energy use (%)



Source: EIA (2015)

According to ECN (2014), the three major forms of final energy relevant for economic growth are electricity power, fuel and processed heat. Energy consumption of the economic sector in Nigerian is divided into the following sectors: (i) industry, (ii) transport, and (iii) residential (household). The household sector represents the largest share of energy usage in Nigeria by nearly 77 per cent as shown in Figure 2.4. It can be seen that the transport, industrial and others sectors consume less than half of residential energy consumption, with their shares ranging from about 5.9 per cent to roughly 8.5 per cent. The sectoral energy consumption in Nigeria contrasts with those of other developing and emerging countries such as Bangladesh, Brazil, Indonesia and South Africa.

Figure 2.4: Energy use by sector



Source: GIZ (2015)

2.4.1 The residential sector

The residential sector is the largest energy consuming sector, representing about 77 per cent of total energy consumed in 2015, and is sub-divided into urban and rural areas. A large amount of the energy consumed in the sector is mostly in the form of biomass mainly consumed by people in rural areas, while residents in urban areas depend on the use of an unreliable electricity supply. Although clean stoves and cookers have been introduced in the rural areas, much investment is still needed to increase access to clean energy in these areas. This case is reversed when compared to other sub-Saharan African countries, such as South Africa, as shown in Figure 2.6.

2.4.2 The industrial sector

The industrial sector comprises the manufacturing, mining, business and trade sectors and accounts for the second largest share of energy use in Nigeria. In Figure 2.4 above, the percentage of energy used by each of these sub-sectors is presented. The figure shows that energy consumed in this sector is small compared to other countries. In the case of South Africa and Brazil, this sector consumed the highest share of energy, which implies a high level of industrialisation.

2.4.3 The transportation sector

The transportation sector represents a small proportion of total energy consumed as seen in Figure 2.4. The energy types consumed in the transportation sector are liquid fuels, such as petrol, diesel and jet fuel. Nigeria is still highly dependent on fossil fuel energy consumption in this sector, making it very difficult to switch from fossil fuels to other sources of energy when compared to other developing economies.

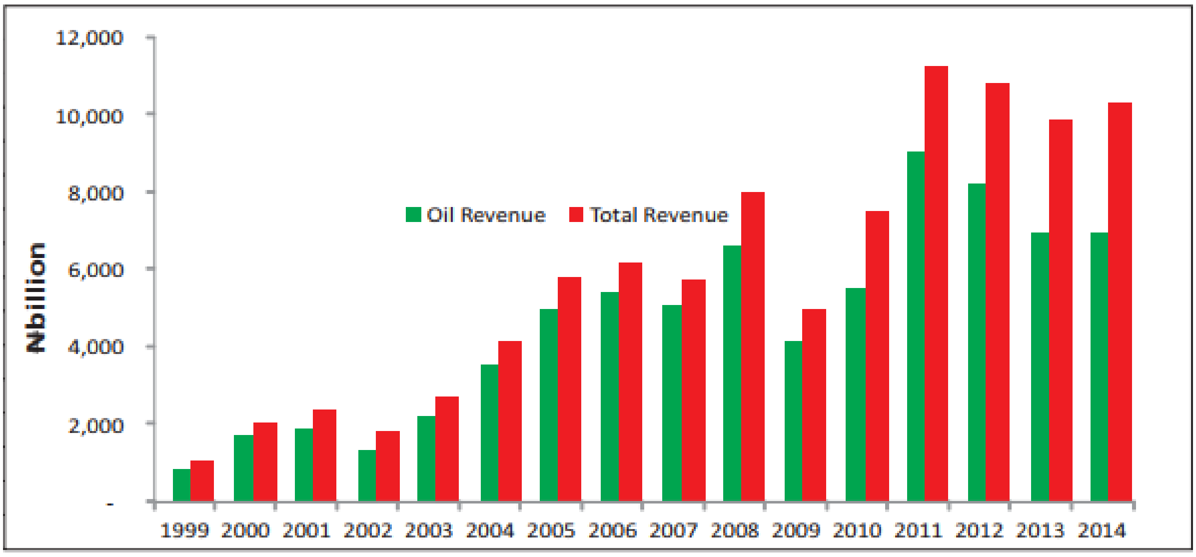
2.4.4 The "Others" sector

This sector is the largest part of the economy, and includes the government, office buildings, financial institutions, shops, recreation and education. Energy consumption in this sector is used mainly for lighting, heating and air-conditioning and the use of office equipment such as computers, fax machines and printers. Although this sector plays a significant role in economic activities, most electricity supply is self-generated by institutions, businesses, etc. However, looking at Figure 2.4, a small proportion of energy is consumed in this sector compared to other countries.

2.5 Performance/contribution of the energy sector to the Nigerian economy

Nigeria is one of the largest African crude oil producers and is ranked among the top five exporters of liquefied natural gas (LNG) globally (EIA, 2013). According to the Nigerian National Bureau of Statistics (NBS), the population estimate was 193 million in 2016, and according to the United Nations the country is predicted to have the world's fourth largest population by 2030. However, the country is mainly dependent on the oil and gas sector to meet its development expenditure, with the sector representing almost 35 per cent of GDP, and petroleum exports revenue representing 90 per cent of total export revenue (ECN, 2013). The size of oil revenue relative to total government revenue is shown in Figure 2.5.

Figure 2.5: Oil and total revenue in Nigeria (1999 to 2014)



Source: CBN (2016)

In 2013, it was recorded that the Nigerian economy was among the fastest growing economies in Africa, having a real growth rate of 5.5 per cent. However, by 2015 growth had contracted to 2.8 per cent after reaching 6.2 per cent in 2014. This was attributed to the decline in global commodity prices that started in 2014 and had an enormous impact on the Nigerian economy which led to the diminishing growth rate in 2015 (CBN Annual Report, 2016). The Nigerian crude oil spot price fell by 44.7 per cent from a peak of US$114.17 per barrel in June 2014 to US$63.19 in December 2014 and further to US$53.10 per barrel in December 2015. The fall in oil prices also exerted pressure on external reserves, leading to a fall of 17.3 per cent in foreign external reserves from US$34.20 billion to US$28.28 billion in 2015 (CBN Annual Report).

According to the CBN Annual Report (2017), the visible reduction in the share of real GDP of the oil sector further resulted in an economic recession by mid-2016. However, an increase in crude oil prices in 2017 along with the exemption of Nigeria from the OPEC output cut saw actual revenue from crude oil and gas sales surpass its prorated target of ₦1,670.82 billion, and resulted in a positive growth rate. GDP at the current basic price in 2017 was ₦94.1 million with oil and gas GDP accounting for 6.4 per cent of this value. Total export from the sector amounted to ₦8.6 trillion which is equivalent to 89.3 per cent of total exports in 2017.

The energy sector plays a significant role in the Nigerian economy as a means of fuelling economic growth, sources of generating government revenues and as an instrument of political intervention at the global level (ECN, 2003). However, shortages in energy supply have restricted socio-economic productivity, limited economic development and negatively influenced the quality of life in Nigeria over the years (ECN, 2015).

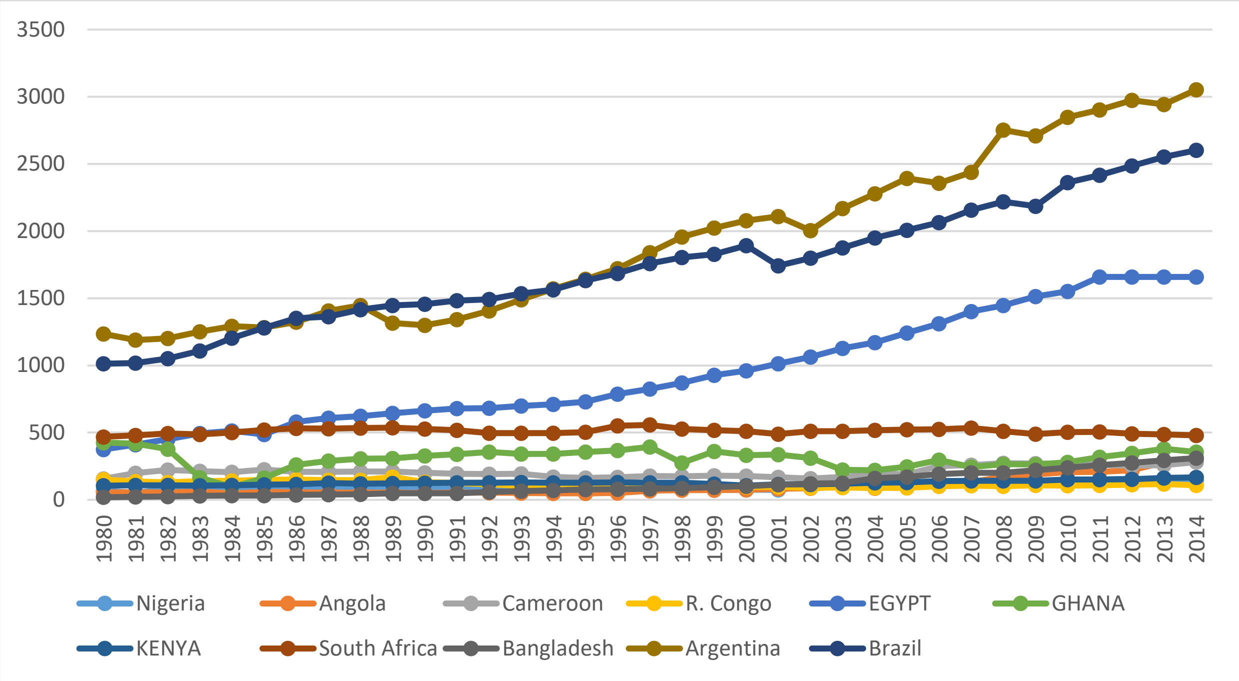
Although Nigeria is highly dependent on revenue generated from oil and natural gas and is a major contributor to foreign exchange earnings, which represented roughly 95 per cent of total exports to the world in 2014 (EIA, 2016), the unpredictable nature of the oil and gas sector has hampered development of the sector. For instance, in 2016 oil production was projected to be 1.833mb/day, compared to 2.13mb/day in the previous year of 2015. This decrease was mostly due to vandalisation in the Niger Delta region leading to a contraction of the sector by 13.65 per cent, higher than the decline of 5.45 per cent in 2015. The effect of this on the oil sector was the reduction in the share of real GDP to 8.42 per cent in 2016, compared to 9.61 per cent in the previous year (NBS, 2017). The fall in oil prices had a huge negative effect on revenue and foreign reserves which contributed to the dwindling economy leading to the recent economic recession in the country.

Compared to other developing countries, the performance of the energy sector has been relatively poor. This is because the sector is highly dependent on the exploitation of biomass resources. Wood fuel is the dominant source of energy consumed in rural areas, and currently represents more than 80 per cent of total energy consumed, and roughly over 50 per cent of total primary domestic energy consumption in the country. The sector also highly depends on imported final petroleum products, while renewable energy sources have been under-exploited. In the past years, wood consumption in most parts of the country has affected the economy negatively and the well-being of the people has been undermined. Overdependence on wood fuel coupled with dwindling oil prices in recent years has crippled both economic activities and the contribution of the sector to total revenue and economic growth (CBN, 2015).

2.6 The electricity sector

According to ECN (2014), final forms of energy needed to drive an economy are electricity, fuel and processed heat. Efforts by the government to transform the country’s electricity sector over the years have not yielded positive results. Given the installed capacity of 13,308MW, electricity demand is estimated at 17,520MW but only 6,158MW were operational in 2014. Out of this, a total of only 3,000MW-4,500MW are in fact produced due to loss of gas, dilapidated infrastructure, energy theft, vandalisation and water shortage (MPWH, 2016). Despite significant investment in the energy sector by the federal government in recent years, the energy contribution in 2014 and 2015 remained relatively low (CBN, 2015). For this reason, various steps are being taken towards achieving the targeted production output of 10GW and 30GW of on-grid power supply from all the energy mix (conventional) sources in 2020 and 2030 respectively, and an additional 8GW to be produced from alternative energy sources by 2030 (MPWH, 2016).

Figure 2.6: Electricity consumption (per capita KWH)

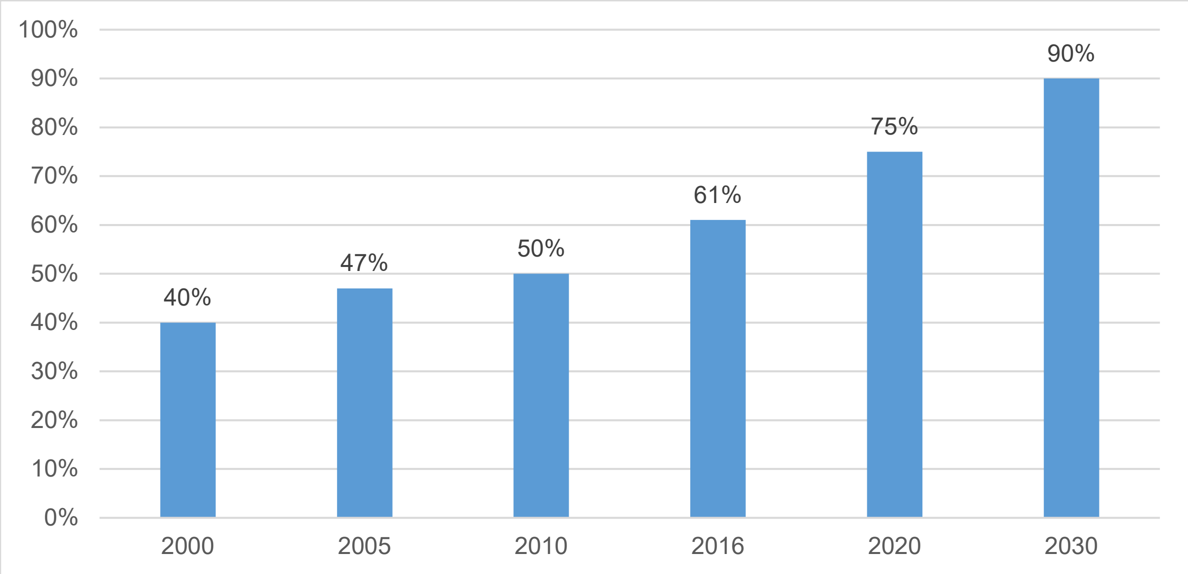


Source: Author's computation (Africa Information Highway data, 2018)

Figure 2.6 compares the electricity consumption in Nigeria with a selection of countries which were selected based on either their high energy consumption profile, as in the case of South Africa, or based on the fact that they are oil exporting countries, as in the case of Angola. Ghana was selected as a West African country that has recently discovered oil. Kenya was selected as the largest economy and highest energy consuming country in East Africa. Cameroon and Republic of Congo were selected as the largest energy consuming countries from Central Africa. Bangladesh, Argentina and Brazil were selected because they are emerging economies such as Nigeria (IMF, 2015). From the figure, it is evident that electricity consumption per capita in Nigeria is among the lowest in the world.

According to OECD/IEA (2017), electricity access in Nigeria was estimated at 61% in 2016, meaning that roughly 74 million people in Nigeria do not have access to electricity (Figure 2.7). The report shows diverse electricity access between rural and urban areas. Rural electricity access is estimated at only 34% compared to 86% for urban centres. Estimates also show that about 115 million people, most of whom live in rural communities, depend on the use of biomass and waste as their main sources of energy supply (NESP, 2016). The government has set goals for improving electricity access for 2020 (75%) and 2030 (90%) as shown in Figure 2.7. But the evolution of electricity access from 2000 to 2016 shows that modest gains have been achieved in this regard and the set targets for 2020 and 2030 are realisable with appropriate policy support.

Figure 2.7: Evolution of electricity access and targets for 2020 and 2030 (%)



Source: FMPWH (2016) and OECD/IEA (2017)

2.7 Energy efficiency in Nigeria

According to the IEA (International Energy Agency), energy efficiency is achieving the same services or level of economic activity with less energy (such as heating/cooling, etc.). The resulting reduction in energy consumption, whilst usually associated with technological changes, can also come about as a result of better organisation and management or improved economic conditions in the sector under investigation (Kohler, 2015). Energy efficiency is key to ensuring safe, reliable, affordable and sustainable energy system for the future (IEA, 2017).

Recently, energy efficiency measures have become important issues informing local and foreign energy policy within the context of changing international energy prices and increasing concerns relating to global warming and climate change (IEA, 2017; UNIDO, 2011). Rising prices of depleting fossil fuels, the recent economic crisis and new international environmental and energy policies are forcing governments, lawmakers and industrial companies to make policies that cut energy wastes and inefficiencies and control energy consumption (Benedetti, Cesarotti and Introna, 2015; Gillingham, Newell and Palmer, 2006). Studies have shown that there is considerable potential for improving energy efficiency, such as the effect on energy security through the adoption of established technologies that are highly cost-effective (Couder, 2015; Sorrell, Mallett and Nye, 2011). However, for most developing countries, achieving energy efficiency for sustainable development still presents a challenge that requires immediate attention.

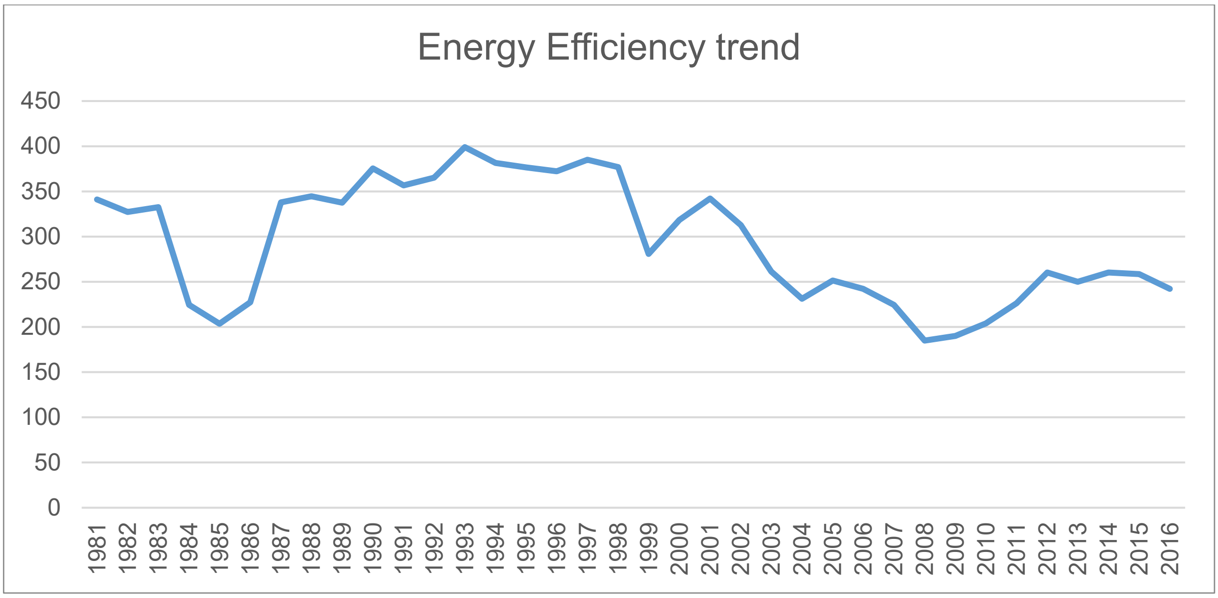
Nigeria has committed to international climate policy negotiations since it became a party to the UN Framework Convention on Climate Change (UNFCCC) in 1994. It also took necessary actions that will reduce the country’s greenhouse gas emissions by 45 per cent below the ‘‘business-as-usual’’ scenario by 2030, and ratified the Kyoto Protocol in 2004. It followed up these efforts recently via its nationally determined contributions (NDCs) to the 2015 Paris Climate Agreement. In the NDC submitted in 2015, Nigeria promised to improve energy efficiency by 2 per cent annually, leading to 30 per cent improvement by 2030 (UNFCCC, 2016). However, energy efficiency is still low due largely to high energy demands to meet energy consumption needs, and the widespread use of inefficient energy technologies (GIZ, 2016).

Figure 2.8 shows the trend of aggregate energy intensity in Nigeria from 1981–2016. Energy intensity decreased in the early 1980s, reducing from 341Btu/$ in 1981 to 204Btu/$ in 1985. This depicts a significant energy efficiency improvement, as the amount of energy used to produce a unit of GDP reduced from 341Btu to 204Btu. However, in the aftermath of the structural adjustment program (SAP) in 1986, the level of energy intensity increased sharply, eliminating the gains from energy efficiency improvements in the earlier years. Energy intensity increased to 344Btu/$ in 1988. This could be as a result of the economic adjustments that took place as a result of the SAP.

Energy intensity gradually increased after reaching a peak of 399Btu/$ in 1993. This meant that by 1993, the Nigerian economy was consuming energy equivalent to 399Btu to achieve $1 of GDP. Since then, energy intensity in Nigeria has gradually reduced even though there have been some fluctuations. The energy intensity was lowest in 2008 at 184Btu/$, which means that the Nigerian economy only needed 184Btu level of energy consumption to achieve $1 of GDP. This is a significant reduction compared to the level in 1993 or 342Btu/$ in 2001.

However, while the reduction in energy intensity during this period (2008) could be interpreted as an improvement in energy efficiency, it was largely due to the effects of the global financial crisis which affected energy consumption worldwide. The global economy experienced a fall in energy intensity during this period. The global financial/economic crisis led to a significant fall in economic output, which also led to a fall in energy consumption that drives the output. As at 2016, energy intensity stood at 242Btu/$.

Figure 2.8: Trend of energy intensity in Nigeria from 1981–2016 (Btu/$)



Source: Author's computation from EIA data

Table 2.5 presents the average energy efficiency trend among selected African countries. The countries were randomly selected from each of the regions in sub-Saharan Africa. An observation from the table is that while in other countries an increase in average energy efficiency is observed, the reverse is the case in Nigeria. Energy efficiency was at its peak in Nigeria during 2000-2004. An explanation for this could be the impact of policies established by the government after the commitment to the Kyoto protocol on sustainable growth. Evidently, these policies have yielded little or no results as average efficiency starts to decrease till date.

Table 2.5: Average energy efficiency trend of selected countries

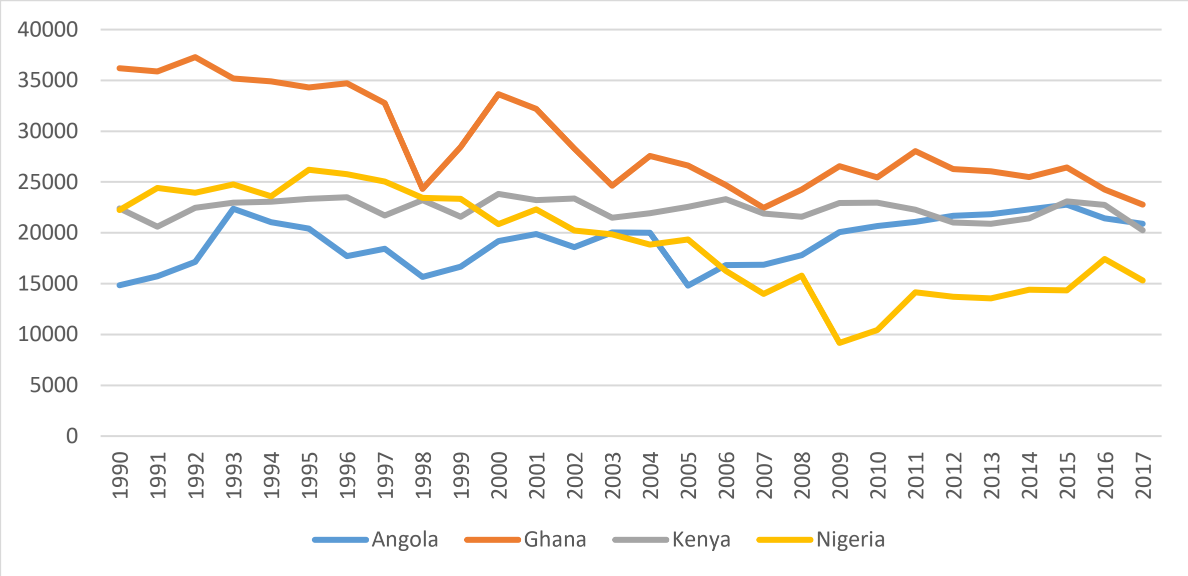
Average	Nigeria	South Africa	Ghana	Kenya	Angola
1990-1994	116081.5	116081.523	22298.54	23791.18	35891.84
1995-1999	119380.7	119380.738	22670.49	24766.48	30906.41
2000-2004	20417.64	112328.815	29268.22	22777.9	19544.32
2005-2009	14914.56	103152.867	24920.81	22459.15	17267.81
2010-2014	13242.91	94239.307	26268.65	21716.3	21512.21
2015-2017	15689.21	88639.1993	24487.83	22030.69	21696.76

Source: Author's computations using EIA data

Figure 2.9 and Table 2.5 present the trend of energy intensity in Nigeria, Ghana, Angola and Kenya. The countries were selected based on either their high energy consumption profile, as in the case of South Africa, or based on the fact that they are oil exporting countries, as in the case of Angola. Ghana was selected as a West African country that has recently discovered oil, Kenya was selected as the largest economy and highest energy consuming country in East Africa. As seen in the figure, average energy efficiency in Nigeria portrays an unstable trend. It showed a declining trend between the periods of 2005 up until 2014, and started to rise again.

A similar trend is witnessed in the case of Ghana, Kenya and Angola. However, South Africa, which seemed to have been doing better than other African countries, has been witnessing a decline in energy efficiency trend in the past decade. Although in the case of Nigeria, energy efficiency may have shown a lower trend than Ghana, Kenya and Angola over time, it is important to note that Ghana, Kenya and Angola are experiencing a higher trend than Nigeria. This implies that unlike Ghana, Kenya and Angola, the energy efficiency trend in Nigeria is very low.

Figure 2.9: Energy intensity trend in selected countries from 1981–2017 (Btu $)



Source: Author's computation from EIA data

A major drawback of using energy intensity to measure energy efficiency is that it assumes that energy is the only economic input, and ignores the important role of labour and capital in economic output. Furthermore, the difference between energy intensity and efficiency is crucial when more than one product or technology is involved. For example, it is not reasonable to compare the energy efficiency of paper production with that of steel production. But it is possible to examine the energy efficiency of a country and compare with other countries or to examine the energy efficiency of an entire sector, such as manufacturing in this case.

2.8 Energy financing options in Nigeria

To build new and broader economic opportunities, increase energy supply to meet energy demand and decrease CO_2 emissions, governments from most developing countries, including Nigeria, pledged to go on a low-carbon development path. However, due to lack of funding from public and concessional sources, the private sector could be used to generate most of the needed funds through significant investments in alternative energy technologies (World Bank, 2012). In Africa, available funding to address under-developed infrastructure needs was calculated to have reached roughly $80 billion in 2013 (APP, 2015). Local public financing involved nearly half of these investments while external financing included private participation in infrastructure (PPI), official development finance (ODF), and Chinese investments comprises the remainder (IRENA, 2016).

Yet the calculated cost of fighting Africa's poor energy infrastructure requires a huge amount of roughly $63 billion in just 2013. According to the African Development Bank estimates, developing countries, particularly African countries, would need a total of $547 billion to finance production/generation, transmission and distribution of electricity to attain universal reliable electricity access by 2030. In 2014, renewable energy investment rose to about $270 billion and the share of RE investment for developing nations increased to about $138 billion (UNEP-Bloomberg, 2015). This increase is expected to last into the future as countries struggle to redeploy and increase the share of RE in their energy mix.

However, financing of the energy sector has become the most critical challenge towards achieving economic growth in Nigeria. In financing alternative energy sources, there are two main issues to be considered: the various sources or options for financing alternative energy, and the most cost-effective financing mechanism. For most developing countries and in the African context, the existence of huge fiscal deficits and challenges at a macroeconomic level coupled with a huge energy infrastructure gap makes it imperative to consider these options carefully for energy financing. The recent economic recession has further constrained the Nigerian government's ability to meet its fiscal inducements for RE projects to generate new sources of revenue or extend existing sources to reap higher revenue. In such circumstances, options to finance RE production would have to be strategically analysed.

One of the challenges investors face in financing RE investment is that RE assets do not lie within the typical asset class space in terms of their risk-reward configurations. Hence it is difficult for typical investors to ascertain the returns commensurate with such investments, particularly when they appear to be more costly in terms of technology relative to traditional assets. Indeed for these reasons, when compared to typical asset classes, RE appears to be a relatively unattractive form of investment (Griffith-Jones et al., 2012). This makes financing options more difficult in the case of RE investment.

Generally speaking, financing options for energy can be obtained from two sources: debt and equity. Debt financing can be obtained from international and domestic sources. If the investor is able to foresee the income revenue of an energy project, financial institutions will provide capital at lower cost, thus lowering the costs for RE supply. A major problem with domestic debt finance is that energy investments are usually capital-intensive and require long-term loans, which are generally difficult to access in Africa, including in Nigeria. In addition the country's financial market for long-term loans is not developed and capitalised sufficiently in terms of liquidity to finance large energy projects. This places further constraints on using domestic markets to finance energy projects as international banks require a substantial return on investment at a lower risk in order to extend finance.

Hence, efforts to overcome these constraints to finance RE projects are imperative and will go a long way in improving energy supply, de-carbonising the sector and generating employment opportunities for sustainable growth in Nigeria.

2.9 Energy sector policy reforms

Over the years, the Nigerian government has managed and formulated energy policies and regulations, operations and investment of the energy sector. Issues such as inefficiencies in the operations and general performance of the sector led to the amendment of the Electricity and National Electric Power Authority (NEPA) Acts in 1998. This was done to eliminate the monopoly of NEPA and attain liberalisation and privatisation of the electricity sector (Ajumogobia and Okeke, 2015). Efforts by the government to reposition the sector led to some actions that included the unbundling of NEPA through the enactment of the Electricity Power Sector Reform Act in 2005. In addition, the Nigeria Electricity Regulatory Commission (NERC) was established in 2005 to foster efficiency through proper regulation of the energy sector, grant licences to market participants, and ensure conformity with market rules and operational guidelines.

The electricity sector reform culminated in the separation of the three arms (generation, transmission and distribution) of the sector. The 2005 Act unbundled the national utility company into a succession of 18 companies which were grouped into six generating companies now known as the Gencos, twelve distributing companies (mostly referred to as the Discos) available in all 36 states of the country, and one national electricity transmission company. This privatisation program by the Bureau of Public Enterprises was aimed at providing and increasing energy generation and consumption, reducing inefficiencies and enhancing growth of the sector (KPMG, 2013).

Several years after the privatisation of the sector, Gencos and Discos and even the transmission company are faced with huge operational challenges, which are evident in the operations and service delivery of these companies. Recently, some of these challenges have been summarised and grouped into categories such as storage capacity, grid insufficiency and instability, poor network infrastructure challenges, tariff challenges and revenue shortfalls, metering challenges, operational challenges, energy theft, funding challenges etc. Due to these challenges the privatisation process which was meant to strengthen the sector has yielded little results, while the objectives of privatisation has been defeated as a result of the inability of the private sector to address some of these challenges that have overwhelmed the success of unbundling the sector.

Therefore, to harness renewable resources, NERC approved the feed-in tariff regulation for renewable-sourced electricity in 2014 in a bid to boost renewable energy production in the country, in line with the Electric Power Sector Reform Act (2005) (CBN, 2015).

Electricity pricing in Nigeria is in two parts: the generation and distribution arms, which are regulated by NERC under the Multi-Year-Tariff-Order (MYTO) principle (NERC, 2015). According to NERC, the guidelines and assumptions on which electricity pricing is based include cost recovery, attraction for both local and foreign investment, security, certainty, return on investment, efficient use of the network and allocation of risks. These principles were all designed and included in the MYTO to attract local and global investors (Rapu et al., 2015). The importance of the principle applied in the MYTO was the ability of the structures to redistribute risk efficiently. The evolution of energy policies in Nigeria is presented in Table 2.6.

Table 2.6: Summary of policy implementation of the energy sector reforms

Timeframe	Polices Implemented
2001	Adoption of the National Electric Power Policy.
2005	Enactment of the Electric Power Sector Reform Act (EPSRA).
2005-2007	Establishment of the National Electricity Regulatory Commission (NERC); formation of the Power Holding Company of Nigeria (PHCN); unbundling of the PHCN into 18 independent companies.
2008-2009	Publication of the Multi Year Tariff Order (MYTO); formation of the Power Sector Reform Committee.
2010-2012	Launch of the Nigerian Vision 20:2020; establishment of the Presidential Action Committee on Power (PACP) and the Presidential Task Force on Power (PTFP); release of the Roadmap for Power Sector Reform; establishment of the Bulk Trader.
2012	MYTO II approved and released

2013	Full privatisation of the generation and distribution subsectors; the transmission subsector retained by Government but its management is currently under concession.
2015	MYTO 2.1 approved and released. Petitions by various consumer groups, evoked by electricity price increases of up to 80%, led to amendment of MYTO 2.1 and a price drop of 50%.
1st Feb. 2015	Commencement of TEM, after NERC declared all conditions precedent listed in the market rules as satisfied.
April, 2015	The National Renewable Energy and Energy Efficiency Policy (NREEEP) policy document launched.
May, 2015	Unbundling of TCN into an Independent System Operator (public) and a Transmission Service Provider (private) begun.
July, 2016	The development of Sustainable Energy for all Action Agenda (SE4ALL-AA).

Source: NESP (2015) and Author's compilations

2.10 Conclusion

Shortages of energy supply has been a challenging and limiting cause to the energy sector and this has slowed economic growth in Nigeria. The deployment of renewable energy has the potential not only to enhance economic growth, but also to deepen the effect of the real sectors of the economy through increased productive activities. A more adequate, reliable, clean and affordable energy supply will improve the modernisation of agriculture which employs a larger section of the population and in turn sustain and increase the quality of life. It will lead to more job creation, development of innovative business ideas and an improvement in social service delivery.

The right policies and strategies will bring about improvements in energy efficiency, resulting in energy security while reducing the negative environmental effects. The energy market is highly volatile and unpredictable. Heavy reliance on fossil fuel as a source of revenue is detrimental to the growth and development of the country. As part of the steps by the current government in the 2017-2020 Economic Recovery Growth Plan (ERGP), the government has outlined the will to diversify and ensure a viable economy and responsibly exploit its natural endowments to guarantee sustainable growth. The costs and benefits associated with diversifying the energy sector for increased energy supply are yet to be adequately explored.

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CHAPTER THREE

ENERGY, GROWTH AND THE ENVIRONMENT: A LITERATURE REVIEW

3.0 Abstract

This essay provides a review of the discussions in the literature of the energy-growth nexus, the Environmental Kuznets Curve (EKC) hypothesis and the costs and benefits of various energy options. The survey highlights the theoretical underpinnings of energy-growth and environment and presents empirical studies supporting each of the energy-growth hypotheses as well as studies supporting the validity of EKC and the costs and benefits of energy options. Generally, the literature shows that there are conflicting views from results on the energy-growth-environment nexus. The survey also shows that most empirical studies focused on either testing the role of energy in driving economic growth or examining the direction of causality between the two variables On the EKC, the majority of the studies focused on developed countries, with little country specific analysis in developing countries.

3.1 Introduction

There are three research strands of the literature discussed in this chapter. The first focuses on the theoretical issues on the link between energy and growth. The second discusses the Environmental Kuznets Curve (EKC) that relates the impacts of economic growth to the environment. The third involves the literature on the economic costs and benefits of energy options.

3.2 Energy-growth nexus

3.2.1 Literature on energy-growth nexus

Energy development refers to the increase in the provision and use of energy services for economic productivity (Toman and Jemelkova, 2003). The production process requires some factors of production that are non-reproducible, while others can be manufactured at a cost within the economic production system (Stern, 2004). According to mainstream economists, land, labour and capital are the essential factors of production, while fuels and natural materials remain the intermediate inputs. However, the provision and consumption of energy services is directly linked to economic growth (Toman and Jemelkova, 2003). These linkages between energy use, other inputs and economic productivity varies significantly as an economy evolve, and this is described as the energy ladder (Barnes and Floor, 1996).

This variation in theory on the linkages between energy use and growth is shown in a simple model of an economy as presented below. This is known as the growth model with natural resources or simply referred to as the neoclassical literature on growth and resources and is expressed as follows:

$$Y = F(K_y, H_y, E) \quad \dots (3.1)$$

$$E = E(K_E, H_E) \quad \dots (3.2)$$

$$H = G(K_H, L) \quad \dots (3.3)$$

Where Y represents the production of final goods and services, K_Y stands for physical capital and $H_Y$stands for human capital, along with another intermediate good, E is energy services. Energy services in turn depend on physical and human capital services, K_E H_E as shown in (3.2). Accordingly, if there is more than one input (capital and natural resources), there are many alternative paths an economy can take and these paths are determined by the institutional arrangements that are assumed to exist.

The neoclassical growth model centres on conditions which permit continuous progress, or at least a non-declining consumption or utility. Technical and institutional situations decide whether such sustainabilities are possible. Technical conditions could mean things such as the mix of alternative energy sources and non-renewable resources, the original endowments of capital and natural resources, and the ease of replacement among other inputs. The institutional setting deals with the market structure (competition versus central planning), the system of property rights (private versus common property), and the system of values regarding the welfare of future generations (Stern, 2004). In this instance, the neoclassical economists are principally concerned in knowing the path and whether institutional measures will bring about sustainability, so that they naturally assume a priori that sustainability is technically possible, and then explore further whether institutional provisions may lead to sustainability if it is technically possible.

Generally, the views of the different economists are explained by the conflicting results of the energy-growth nexus. While the conventional or mainstream growth theories focused on institutional limitation to growth as ways of mitigating the scarcity of resources, ecological economists lean towards and tend to focus on the quantifiable basis of the economy. Accordingly, the act of substituting manufactured capital for resources and technological change could possibly get more production out of a restricted resource production input and avoid the inadequate capacity of natural environments to absorb the impacts of energy and resource use by decreasing those effects. But if these two methods are restricted, then limited resources or undue environmental pollution may negatively affect growth.

Therefore, the energy-economic growth nexus can be analysed under four hypotheses. The first theory states that energy usage plays a crucial role in economic growth. This is known as the growth hypothesis, which was advanced by ecological economists who argued that technical advancement and other physical factors could not possibly substitute for the important function of energy in production activities (Stern, 1993). This implies that a country's economic growth depends largely on energy usage, so that any energy conservative policies may have a negative effect on economic growth. According to this hypothesis, energy consumption plays important direct and indirect roles in economic growth and acts as a complement to factors of production (labour and capital) in the production process. Thus, energy used is a restraining factor to economic growth, so that any shocks to the energy source will have a harmful influence on economic growth (Ozturk, 2010).

The second hypothesis is the feedback hypothesis, which asserts the existence of a bi-directional causal link between energy used and growth. This theory reflects the interdependence between energy and growth, and upholds that energy used and economic growth are mutually determined and affected at the same time. Although bi-directional connection means that an energy conservation policy may still be harmful to economic growth at an aggregated level, energy policy must be judiciously thought out with careful regulations, since one-sided policy selection is detrimental for economic growth (Yildirim and Aslan, 2012).

Another view of the causality link between growth and energy is the neutrality hypothesis. The neoclassical economists argued that energy use does not influence economic growth (Stern and Cleveland, 2004). That is to say, both energy use and economic growth are neutral with respect to each other, meaning that capital and labour are the primary factors of production while energy is simply considered as an intermediate input of production which is used up in the entire production process (Tsani, 2010; Alam, Begum, Buysse and Hulenbroeck, 2012). This theory postulates that no causality exist between energy use and economic growth, implying that energy conservation policies will have no effect on growth.

Finally, the fourth hypothesis, known as the conservative hypothesis, states that a uni-directional connection runs from economic growth to energy consumption. In this regard, policies aimed at conserving energy use to reduce carbon emissions, improving energy efficiency measures and designing demand management policies to reduce energy usage and waste may have little or no negative effect on economic growth (Sharma, 2010). This theory is confirmed if a rise in real GDP leads to a rise in energy used. In the case of an energy-dependent economy, energy conservative policies that could be implemented to reduce emissions may not influence economic growth.

3.2.2 The empirical literature on the link between energy and growth

A group of studies supporting the conservation hypothesis on the link between energy and growth includes Kraft and Kraft (1978), who investigated the relationship between energy and growth using the Granger Causality test for the period 1947-1974. The study provided reason to support a uni-directional long-run linkage running from GDP to energy consumption for the USA. Ewing et al. (2007) applied the ARDL bounds testing cointegration approach to test the long-run relationship between energy and growth in the United States. The results suggested the existence of unexpected shocks to coal, natural gas and fossil fuel energy sources which had the highest impacts on the variation of output. Cheng et al. (2009) focused on the linkages between renewable energy consumption and economic growth for 30 OECD countries under different economic growth regimes using a panel threshold regression model. Their results indicated that economic growth positively Granger-causes renewable energy consumption. Other studies that support the hypothesis include Cheng et al. (2014), Abalaba and Dada (2013), Ahmad et al. (2012), Mehrara and Musai (2012), Mehrara (2007) and Soytas and Sari (2003).

Another group of studies which support the growth hypothesis includes Apergis and Danuletiu (2014), who employed the Canning and Pedroni (2008) long-run causality test to examine the relationship between renewable energy and economic growth for 80 countries and found evidence that supports the growth hypothesis. Apergis and Payne (2009) examined the relationship between energy consumption and economic growth for six Central American countries using a multivariate framework. Their results showed the presence of both short-run and long-run causality from energy consumption to economic growth. Odhiambo (2009a) investigated the causal relationship between energy consumption and economic growth in Tanzania. The bounds test found that there is a stable long-run linkage and a unidirectional causality from total energy consumption to economic growth. Payne (2010b, 2010c) employed the Toda–Yamamoto causality test to examine the causal relationship between biogas energy consumption and real output in the U.S. economy over the period 1949–2007, and found a unidirectional causality running from biogas consumption to real output, also confirming the growth hypothesis. Other studies that have supported this hypothesis are Wandji (2013), Alaba and Dada (2013), Zhan-wei and Xun-gan (2012), Stern (2010), Odhiambo (2009b), Lee and Chang (2008) and Lee (2005).

There is also a fairly substantial group of empirical studies supporting the feedback theory. Mahadevan and Asafu-Adjaye (2007) employed a panel error correction model using data for 20 net energy importers and exporters from 1971 to 2002. The study found the existence of bi-directional causality between economic growth and energy consumption. Apergis and Payne (2010a and 2010b) conducted a study to investigate the causal relationship between renewable energy consumption and economic growth for a panel of thirteen OECD countries using panel cointegration and error correction mechanism (ECM) for the period 1985–2005. The results revealed bi-directional causality between renewable energy consumption and economic growth in both the short and long run, which confirms the feedback hypothesis. Other studies with similar findings are Cheng et al. (2015), Gollagari and Rena (2013), Apergis and Payne (2012), Wang et al. (2012), Shahbaz, Zeshan and Afza (2012), and Apergis and Payne (2011).

Other empirical studies also confirm the neutrality hypothesis. Payne (2009a) applied Toda–Yamamoto tests to examine the nature of the causal link between renewable energy consumption, non-renewable energy consumption and real output in the United States. The study used annual data for the period 1949–2006 and found no causality between the variables. Halicioglu (2009) studied the relationship between energy consumption and income in Turkey and found evidence to support the neutrality hypothesis of no causal relationship between energy consumption and economic growth.

Payne (2010a) provided comprehensive surveys on the literature of causal relationship between energy consumption, electricity consumption and economic growth. The results show that there is no clear consensus whether particular countries or groups of countries are energy-dependent or energy-neutral. Bowden and Payne (2010) also utilised the Toda–Yamamoto long-run causality approach to test the causality between renewable energy consumption, non-renewable energy consumption and real output over the period 1949–2006. Their results indicated no causal relationship between commercial and industrial renewable energy consumption and real output.

There are also studies with mixed results in the literature. Akinlo (2008) examined the causal relationship between energy consumption and economic growth for eleven countries in sub-Saharan Africa, and found mixed results for the various countries. The Granger causality test based on the vector error correction model (VECM) showed that a bi-directional relationship exists between energy consumption and economic growth for Gambia, Ghana and Senegal. However, the Granger causality test showed that economic growth Granger-causes energy consumption in Sudan and Zimbabwe, while the neutrality hypothesis was confirmed for Cameroon, Côte d'Ivoire, Nigeria, Kenya and Togo. He further suggested the need for each country should formulate appropriate energy conservation policies taking into cognisance her peculiar condition. Sharma (2010) also employed dynamic panel data models to examine the impact of electricity and non-electricity variables on economic growth for a global panel consisting of 66 countries for the period 1986–2005. The study found the impact of electricity and non-electricity variables on growth are mixed.

One of the potential reasons for the inconsistencies in the findings on energy-growth nexus is the diverse methodological approaches adopted in the literature (Ozturk, 2010; Apergis, 2018). Over the years, several methods have been adopted to investigate the link between energy and growth (see Table 3.1), including time series and panel data methods. Of the time series studies, a number of studies have focused on addressing the causality between energy and growth. For these studies, the Granger causality technique was prominent. However, the emergence of new causality tests such as Sims causality, Hsiao causality tests and Toda-Yamamoto has attracted the attention of researchers in the literature. For cointegration-based causality tests, the ARDL method has been widely used in the literature, due to the relaxation of the requirement that all the variables must be integrated of the same order as well as the robustness of the method and its suitability for small samples (Narayan, 2005; Nkoro and Uko, 2016). Ozturk (2010) suggests that to avoid conflicting results and provide reliable findings, authors should use the ARDL method, two-regime threshold co-integration models, panel data approach and multivariate models.

Table 3.1: Chronology of methodology on energy-growth nexus literature

Study/Authors and Year	Methodology	Period	Country	Findings
Kraft & Kraft (1978)	Sims causality	1947–1974	USA	GDP→EC
Aqeel & Butt (2001)	Hsiao causality	1955–1996	Pakistan	EC→EM; EC↔Y Y→OC
Sari & Soytas (2004)	GEVD	1969–1999	Turkey	EC→GDP
Ewing et al. (2007)	ARDL		USA	EC → GDP
Asafu-Adjaye (2007)	Panel	1971–2002	20 countries	EC↔ GDP
Akinlo (2008)	Panel		11 countries	Mixed results
Cheng et al. (2009)	Toda-Yamamoto	1949–2006	USA	EC→GDP
Payne (2009)	Toda-Yamamoto	1949–2006	USA	No causality
Bowden and Payne	Panel causality	1971–2005	51 countries	GDP ↔ RE
(2010)	test	1985–2005	20 OECD	EC↔GDP
Ozturk et al. (2010)	Panel		countries	
Sharma (2010)	Dynamic panel	1986-2005	66 countries	Mixed results
Payne (2010)	Toda–Yamamoto	1949–2007	USA	EC → GDP
Apergis and Payne (2010)	Panel	1985–2005	13 Eurasian countries	GDP ↔ RE
Lee and Chiu (2011)	Panel	1971–2006	6 developed	Oil prices↔GDP↔Nuclear
Apergis and Payne (2009)	Panel	1980–2006	countries 6 Central American countries	EC → GDP
Odhiambo (2009)	ARDL		Tanzania	EC → GDP
Apergis and Payne (2012)	Panel	1990–2007	80 countries	GDP↔ EC (RE, NRE)
Tugcu et al. (2012)	ARDL approach for cointegration;	1980–2009	G7 countries	The relationship is different for countries and varies with specification
Wesseh and			Liberia	EC↔GDP
Zoumara (2012)	Bootstrap	1980-2008	UAE	79% feedback; 2% conservation;
Hatemi-J (2012)	Bootstrapping			19% neutrality
Dagher and	Hsiao, Toda-	1980–2009	Lebanon	EC ↔ GDP
Yacoubian (2012)	Yamamoto	1968–2008	Turkey	Y↔EC
Aslan (2014)	Bounds test, ECM		80 countries	EC → GDP
Apergis and	Canning and			
Danuletiu (2014)	Pedroni (2008)	1974–2014	Turkey	OC→Y
Terzi & Pata (2016)	causality test Hsiao, UVAR, TYVAR causality			
Bhattacharya et al. (2016)	Panel estimation techniques	1991–2012	38 countries	RE→GDP
	ARDL		10 EU countries	RE ↔ GDP
Marinaş et al. (2018)		1990–2014		

Notes: →, ↔ and —— represent, respectively, unidirectional causality, bidirectional causality and no causality. Abbreviations are defined as follows: EC as Energy Consumption; GDP as Gross Domestic Product.

3.2.3 Summary of literature review on energy-growth nexus

A review of the different strands of literature show that there exist well-documented studies in the energy-growth nexus literature, which have been done mostly on developed and developing economies in the past decades (Kraft and Kraft, 1978; Soytas and Sari, 2003; Ewing et al., 2007; Odhiambo, 2009; Abalaba and Dada, 2013; Zrelli, 2017). However, these studies have mainly focused on the causal direction between energy resources and economic growth and not the impact of disaggregated and aggregated energy sources on economic growth, particularly in Nigeria. To the best of my knowledge, while studies that have disaggregated energy sources exist (Tugcu et al., 2012; Tugcu, 2013; Pata and Terz, 2016; Destek and Okumus, 2017; Bhat, 2018), few or no studies such as this have been found in Nigeria, which is a net exporter of fossil fuel.

Although some studies have examined single countries (Kraft and Kraft, 1978; Ewing et al., 2007; Odhiambo, 2009; Payne, 2010), others have studied several countries simultaneously in a panel data analysis framework (Mahadevan and Asafu-Adjaye, 2007; Akinlo, 2008; Apergis and Payne, 2010; Apergis and Danuletiu, 2014). This is usually done by aggregating energy resources used as a proxy for energy consumption, or sometimes more disaggregated energy levels (e.g. residential, commercial, etc.) or specific energy sources (coal, nuclear, etc.). Obvious trends in the literature seemed to follow bivariate analysis involving two variables: energy consumption and GDP (Altinay and Karagol, 2004; Ghosh, 2002; Soytas and Sari, 2003; Yoo, 2005) as noted in a recent survey by Payne (2010). Some other studies have conducted multivariate analyses (Asafu-Adjaye, 2000; Bloch et al., 2011; Masih and Masih, 1997, 1998; Apergis and Payne, 2009; Oh and Lee, 2004; Stern, 2000; Wolde-Rufael, 2009). Few studies on the impact of disaggregated energy sources (renewable and non-renewable) on growth have employed ARDL in developing countries such as Nigeria. Thus, this current study seeks to fill this identified gap by focusing on Nigeria.

3.3 The Environmental Kuznets Curve (EKC) hypothesis

While energy consumption is a significant driver of economic growth, the impact of economic growth on environmental quality has also enjoyed considerable attention in the literature. However, in spite of the strong link between energy use and growth, there are several paths through which the environmental influence of economic growth can be bridged. For example, a move from lower to higher quality energy options may not only reduce the total energy necessary to produce a unit of GDP, but may also reduce the environmental impacts of energy consumption.

Global warming and climate change has generated much debate and concerns over the impacts of economic growth on the environment. To some, a growing economy which depends on energy consumption will automatically translate into greater environmental degradation and the only way to environmental quality will be to reduce population and consumption (Stern, 2004). Others have argued that the process of substitution and innovation could lead to environmental quality. Further, mainstream economists believe that environmental quality and economic growth are conflicting goals for developing economies.

The diverse views further generated much concerns and were the highlight of the 1972 UN World Conference on the Environment in Stockholm, where it was projected that developing economies do not have adequate resources to achieve environmental quality and growth at the same time, as development was required to meet environmental quality. This was the core issue in the empirical research that is now known as the Environmental Kuznets Curve (EKC).

The EKC hypothesis establishes that there is an inverted U-shape association between environmental degradation and income. In this case, environmental pollution rises at the early stages of economic development and falls at the later stages. This hypothesis emerged in the early 1990s from the work of Grossman and Krueger (1991) and Shafik and Bandypadhyay (1992) for the World Bank. In the report it was argued that the view that greater economic activity hurts the environment is based on static assumption on technology, taste and environmental investments and that as incomes increases, the demand for improvements in environmental quality increases as well as the resources available for investment.

Beckerman (1992) noted that there was enough evidence that economic growth most often reduces the quality of the environment in the early stages of economic progress, but that in the end the best – and probably the only – way to reach environmental quality in most countries will be to become rich. To this end, the EKC has been interpreted as implying that no effort should be put into adopting environmental policies in developing countries, for when these countries attain a certain level of richness, environmental difficulties will be addressed by policies adopted at that later time.

Therefore, based on this hypothesis, economic growth could lead to environmental degradation through three different channels: scale effects, composition effects and technological effects (Grossman and Krueger, 1991). Theoretically, in order to attain more output in the production process, more inputs are required and thus more natural resources are used up. This results in more wastes and emissions as by-products, which also contributes to the degradation of environmental quality. Thus, where there are no changes in the structure or technology of the economy, pure growth in the scale of the economy would result in increased pollution and other environmental impacts (Dinda, 2004). This is known as the scale effect.

When an economy develops, the structure of the economy will change and gradually move towards the use of cleaner technologies in productive activities that produce less pollution due to the composition effect. The gradual move towards cleaner technologies occurs at the point when environmental degradation starts to rise and the structure of the economy begin to change from rural to urban or from agricultural systems to industrialisation. Environmental degradation starts to fall with more structural changes from energy-intensive industries to services and knowledge-based technology intensive industries. Thus, as rich countries invest in research and development, it brings about technological progress with each level of economic growth, and dirty and obsolete technologies are replaced by new and cleaner technology, which improves environmental quality (Beckerman, 1992).

Based on this EKC model, the standard equation is illustrated as follows:

$$\ln(E/P)_{it} = \alpha_i + \gamma_t + \beta_1 \ln(GDP/P)_{it} + \beta_2 (\ln(GDP/P))^2{}_{it} + \varepsilon_{it} \qquad \ldots (3.4)$$

Where E is emissions, P is population, and Ln indicates natural logarithms. The first two terms on the right hand side are intercept parameters which vary across countries or regions i and years t.

Based on the EKC hypothesis, the signs and values of β_1 and β_2 indicate the different functional forms: when $\beta_1 = \beta_2 = 0$, this means that there is a level relationship; when $\beta_1 < 0$ and $\beta_2 = 0$, this implies a monotonic decreasing linear relationship; when $\beta_1 > 0$ and $\beta_2 = 0$, then there is a monotonically increasing linear relationship; when $\beta_1 < 0$

and β_2 > 0, this implies a U-shaped relationship; when β_1 > 0 and β_2 < 0, there seems to be an inverted U-shaped relationship; and when GDP = -β_1/2β_2 then CO_2 is at its peak which is the turning point or the peak of EKC. Since renewable energy is expected to reduce CO_2 emissions, its coefficient is also expected to be negative.

The argument for the EKC is based on the fact that as an economy grows, efforts to create awareness of environmental problems is low and so environmentally-friendly technologies are not available. However, with increased productive activities, the rate of resource exhaustion begins to exceed the rate of resource renewal, and waste generation increases in quantity and toxicity (Dinda, 2004). So greater levels of economic growth, with continued structural changes leaning towards information-intensive industries and services, along with enhanced environmental awareness, implementation of environmental regulations, application of cleaner technology and more environmental expenditures, will bring about the levelling-off and a gradual reduction in environmental degradation (Wolde, 2015).

Therefore, the EKC model assumes a significant natural resource depletion and waste accumulation with a rapid increase in economic growth and industrialisation (Panayotou, 1997). During this stage, a positive relationship exists between economic growth and environmental degradation. That is, the more income increases, emissions also increase up to a point where a certain threshold level of income is reached, after which emissions begin to decline. Hence, industrial structure optimisation, technology improvement, energy efficiency and information diffusion are viewed to reduce environmental degradation with further economic growth (Cheng, 2014).

However, the confirmation of that automatic threshold point has been empirically challenging. The reduction of resource intensity and or new ways of fuelling growth imply the use of cleaner energy. Traditionally, economic growth based on resource intensification is focused on the use of fossil fuel. Therefore, the obvious predicament faced by most developing countries that are rapidly embarking on growth-enhancing and industrialisation policies, is the need to simultaneously grow and decarbonise the economy. Hence, the more rapidly an economy grows, the more the consumption and use of natural resources and the more the environmental degradation. Thus, embarking on economic growth may present a challenge for environmental protection, especially as countries need intensive technological support to follow a sustainable development path.

3.3.1 The empirical studies on EKC

Several studies have tested the validity of the EKC in various countries and different results have been found, particularly for low and middle income countries. This study has grouped the empirical studies into three groups: studies that support the validity of the EKC, studies that found no existence of EKC, and studies from low and middle income countries. By grouping empirical studies, the study investigated the methods, variables and contextual issues that influenced the results of such studies. The strand of studies that supports the validity of the EKC includes Al-Mulali, Saboori and Ozturk (2015), who investigated the existence of the EKC hypothesis in Vietnam during the period 1981–2011. Their results showed evidence of the pollution haven hypothesis in Vietnam because accumulation and use of capital increases pollution. Hami-Haggar (2012) explored the long-run and causal relationship between greenhouse gas emissions, energy consumption and economic growth for the Canadian industrial sectors. The results showed a non-linear relationship between greenhouse gas emissions and economic growth, which is consistent with the EKC. Acaravci and Ozturk (2012) found positive long-run elasticity of carbon emissions with respect to real GDP and negative long-run elasticity estimates with respect to the square of per capita real GDP at 1% significance level for Denmark and 5% significance level for Italy, supporting the validity of the EKC. Other studies with results supporting the validity of the EKC are Bölük and Mert (2015), Cheng (2014), Sulaiman et al. (2013), Shahbaz et al. (2013), Shahbaz et al. (2012), Arouri et al. (2012), Menyah and Wolde-Rufael (2010), Abdulai and Ramcke (2009) and Apergis and Payne (2009a).

However, some studies also found no evidence for the existence of the EKC hypothesis. Ozturk and Acaravci (2010) examined the long-run and causal relationship between economic growth, carbon emissions, energy consumption and employment ratio in Turkey. The results for the existence and direction of Granger causality show that neither carbon emissions per capita nor energy consumption per capita cause a change/increase in real GDP per capita in Turkey. Chen (2007) arrived at a different result on the EKC in China. Using a reduced form model based on provincial panel data, the study analysed the relationship between GDP per capita and the emissions of five kinds of industrial pollutants (solid wastes, waste water, SO_2, soot and smoke), and concluded that the relationships were mixed on the types of pollutants and regions. Zhang and Cheng (2009) found that that neither carbon emissions nor energy consumption lead to economic growth. Other studies with similar findings are Alege and Ogundipe (2013) and Agras and Chapman (1999).

The bulk of studies from low and middle income countries showed varying results regarding the existence of the EKC hypothesis. Wolde (2015) studied the relationship between economic growth and environmental degradation in Ethiopia using time series data from 1969/70 to 2010/2011 and the VECM analysis approach, and found the existence of EKC. Apkan and Chuku (2011) examined economic growth and environmental degradation in Nigeria, using the ARDL bounds test. The results did not support the EKC hypothesis but rather found an N-shaped relationship. Cole and Neumayer (2005) examined the implications of the EKC hypothesis on pollution trends in less developed countries (LDCs). They found evidence that the emission reductions in developed countries are as a result of the export of pollution-intensive domestic production to LDCs, suggesting that LDCs may not be able to follow the postulated EKC hypothesis.

3.3.2 Summary of literature review on the energy-growth-environment nexus

The link between energy consumption, economic growth and environmental degradation have been widely researched in the literature. Usually this has been within the ‘‘Kuznets curve’’ framework, and have thus included emissions as a third variable in the model (Panayotou, 1997; Hami-Haggar, 2012; Menyah and Wolde-Rufael, 2010; Shahbaz et al., 2013; Alege and Ogundipe, 2013 and Wolde, 2015). These studies have yielded different results even for the same country and these mixed results have been attributed to the differences in model specifications, sample periods, estimation and testing methodologies (Apergis and Payne, 2011). Recognising that increased economic growth may not be an automatic response to environmental quality for developing economies, particularly for net oil export countries such as Nigeria, and considering country specifics, this study contributes to the literature by examining the validity of EKC in Nigeria using the ARDL model.

Table 3.2 summarises some earlier relevant studies with some main features including methodology employed and main findings. It can be seen from this table that although earlier studies, such as Yusuf (2014) and Alege and Ogundipe (2013), have investigated the case of EKC in Nigeria, using aggregated data at country level, none of these studies have calculated the threshold point on certain major oil net exporters such as Nigeria. This study identifies and fills this gap by examining the relationships between energy consumption, economic growth and CO_2 emissions in Nigeria, and by calculating the threshold point.

Table 3.2: Empirical literature review on energy–growth–environment nexus

Study	Methodology	Period	Country	Findings
Ang (2007)	Johansen–Juselius, ARDL bounds test, EKC, VECM	1960–2000	France	EC→GDP Inverted U-shaped curve
Halicioglu (2009)	ARDL bounds test, Johansen–Juselius, VECM	1960–2005	Turkey	CO_2↔EC, CO_2↔Income
Apergis and Payne (2009)	Pedroni cointegration, EKC, panel VECM	1971–2004	Six Central American countries	EC↔GDP, EC→CO_2
Jalil and Mahmud (2009)	ARDL bounds test, EKC, VECM	1975–2005	China	Income→CO_2, Square of income→CO_2, Inverted U-shaped
Zhang and Cheng (2009)	Toda–Yamamoto	1960–2007	China	GDP→EC EC→CO_2
Lean and Smyth (2010)	Johansen Fisher panel cointegration EKC, panel VECM	1980–2006	ASEAN countries	CO_2→EC, Inverted U-shaped Curve
Phimphanthavong	EKC Method	1980–2010	Laos	CO_2↔GDP
		1970–2011		GDP→CO_2
Alege & Ogundipe	fractional cointegration analysis	1981–2011	Nigeria	EC↔GDP, EC→CO_2
Yusuf (2014)	Restricted Error Correction Model (VAR)	1969/70–2010/2011	Nigeria	GDP→CO_2, Inverted U-shaped Curve
Wolde (2015)	VECM analysis approach		Ethiopia	

Note: EC refers to energy consumption, VAR represents vector autoregressive model, VECM denotes vector error correct model, ARDL refers to autoregressive distributed lag procedure and EKC refers to Environmental Kuznets Curve.

3.4 Literature on costs and benefits of energy options

Although energy consumption is an important driver of economic growth, it is also claimed to be detrimental to environmental quality. Thus, there is a need for alternative or renewable energy consumption, which is premised on its ability to the meet future energy demands and achieve economic sustainability. However, the diffusion and deployment process has been very slow over the years due to low prices of fossil fuels and entry barriers for renewables in the energy market. Thus rigorous efforts and measures are required to accelerate the development and utilisation of renewable energy, and increase its contribution to the current energy portfolio mix.

Over the years, global market prices for conventional energy are most often lower than the prices of energy produced from renewable sources such as solar, wind and biofuels (REN21, 2012). Unfortunately, these market prices do not take into account the real costs of the energy produced, as they ignore the external costs to society due to pollution from emissions and its resulting problems, including harm to public health and the environment. According to EIA (2016), accounting for these externalities may more than double the cost of some conventional energy sources, making them more costly than renewable energy sources.

Lockwood, Kuzemko, Mitchell and Hoggett (2013) pointed out that the processes of transition may not come about easily as they occur in a multi-dimensional space, due to factors such as institutional rules, economic requirements and political negotiations as well as social and cultural rules and expectations. Hence, to analyse the renewable energy formation of social and technical elements which comes with new innovations, and are locked-in on sunk investments, behavioural patterns, bestowed interests, infrastructure, favourable subsidies and regulations, transition will be difficult. In order words, transformation may be difficult to come by because of regulations, infrastructure, user practices and preservation networks which are all connected to the existing technology. At this level, change and innovation processes tend to occur within the regimes to be incremental, i.e. new innovations are consistently adapted to suit the existing socio-technical configurations of the regime (Schot and Geels, 2008). According to them, transition is possible but costly, and has historically been achieved on numerous instances.

Based on this analysis, it is possible to infer that there is no straight path to achieving sustainable growth, but that there could be an optimal energy portfolio mix (renewable and conventional) with viable energy options for increased energy supply. Unlike some previous studies that have studied the role of the various technologies in different perspectives with various techniques of multiple criteria decision making (MCDM), the next section presents review of empirical literature on methods employed for the evaluation of costs and benefits associated with energy options towards achieving optimal energy supply.

3.4.1 Empirical literature on energy options

Studies on energy options based on Cost Benefit Analysis (CBA) include Krozer (2011), who assessed the costs and benefits of renewable energy use in electricity generation in the EU during the low oil price period of 1998-2002 and high oil price period of 2003-2009. The results showed that during high and quickly increasing oil prices, the correlations between the changes in consumers' electricity prices and the growth of renewable energy use indicates that the large and growing use did not increase the prices but decreased the consumers' electricity prices in several EU countries. It was said that renewable energy enabled input diversification in electricity generation, which reduced the costs. Banerjee et al. (2012) combined CBA and standard thermo-economic analysis to analyse seven decentralised energy systems for small Indian rural communities. The study generated household and irrigation electricity as well as a secondary product or service, which in some cases utilised waste heat from the electricity generation process.

Porter and Williams (2006) used CBA techniques to carry out a comparative analysis of the costs and benefits of three hydropower development options which provide equal levels of service to rural communities. The results showed that investment is recovered 25 per cent faster where some very small hydro-power systems are used instead of using one bigger scheme, and the level of investment required for the bigger scheme is far larger. Gwavuya et al. (2012) assessed the costs of energy generation from major energy sources (firewood and dung) in rural Ethiopia by evaluating the economic potential of biogas as an alternative in addressing both energy and food security challenges. Results showed that households in rural areas mostly collect their own fuel, with female household members being mainly responsible for the chore. Hence investment in biogas plants saves time and energy, and further increases the supply of slurry that is used as fertilizer in agricultural production. A cost benefit analysis of biogas plants yields positive net present values for households collecting their own energy sources. Another study is Manzo and Salling (2016).

Several other studies on energy options based on life cycle cost analysis include Johnson and Ogunseye (2017), who investigated the production performance of grid-connected photovoltaic (PV) system design for local government offices in Nigeria in order to know the amount of electric power generated each day of the year. The analysis revealed that the PV system's daily production far exceeds the energy demand of the local government offices. Agajelu et al. (2013) investigated the LCCA of a diesel/PV hybrid power generating system and found that of the three power systems considered, the analysis of the hybrid system has the lowest life cycle cost and cost of energy. Dale (2013) carried out a comparative analysis of life-cycle analysis (LCA) on the cost of energy of three renewable technologies: solar PV, concentrating solar power (CSP), and wind. The findings showed that wind energy has the lowest energy costs, followed by CSP and then PV.

Lutz et al. (2006) also employed LCCA of an energy efficiency options for residential furnaces and boilers. Their results show that efficiency improvement relative to the baseline design can reduce the life cycle cost in each of the product classes considered. Kirmani et al. (2010) investigated the techno-economic feasibility of a standalone PV system to electrify a rural household in India. Using the LCCA to assess the economic viability of the systems, the study showed that it is economical to use PV systems to electrify rural sites in India. Other studies include Koundouri et al. (2017), Shih and Tseng (2014), Singh, Pant and Olsen (2013) and Evans, Strezov and Evans (2009).

Another group of literature on energy options covers the real options analysis (ROA) technique used to assess the viability of the various energy options. Agaton (2017) analysed energy investment scenarios using the ROA approach to compare the attractiveness of investing in RE rather than the continuing use of coal for electricity generation. The study concluded that REs are better options than continuing the use of coal for electricity production in the Philippines. Locatelli et al. (2016) assessed the technical and economic feasibility of investing in Electrical Energy Storage Systems (EESS) operating price arbitrage and short-term operating reserves. The results show that the implementation of ROA increases the economic performance of EESS.

Kjaerland (2007), Davis and Owens (2003), Cox et al. (1979), Siddiqui et al. (2007) and Kumbaroğlu, Madlener and Demirel (2005) employed ROA and found that many of the factors affecting RE deployment include non-renewable energy costs, cost of renewable energy itself, research and development expenditure on RE, improvement of RE technologies, and the demand for renewable energy. These studies further established that the real options form of appraisal model is more suitable for evaluating the investment value of renewable energy technological development.

3.5 Summary of literature review

The study reviewed three of the methods commonly used in the literature and was able to establish that renewable energy sources are not just an important driver of economic activities, but are now cost-competitive when external costs are considered for fossil energy sources. However, there are factors affecting renewable energy usage which include, among others, the cost of non-renewable energy sources, the cost of renewable energy itself, lack of research and development on renewable energy, improvement of renewable energy technologies, and the demand for renewable energy. It was noted that studies employed different methods to cater for the deficiencies in methodologies. However, despite the methods employed, empirical studies seem to lean towards the need to adopt energy options for optimal energy supply.

In general, this chapter reviewed the literature on energy consumption, economic growth and their impact on environmental quality in the long run. An important observation is that although energy consumption, particularly consumption of fossil fuel, is important for economic growth, it is detrimental to the environment if adequate policies are not in place. Further consideration of external costs makes other forms of renewable energy more competitive in bridging the deficit gap. However, for developing countries such as Nigeria, where in the midst of huge energy resource endowments there is a large energy deficit and low industrial and economic development, energy policies would have to be well crafted with a structural transformation and development agenda in mind. This would entail the use of the most available, less costly and efficient energy resource available for energy supply expansion.

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CHAPTER FOUR
ALTERNATIVE ENERGY CONSUMPTION AND ECONOMIC GROWTH IN NIGERIA

4.0 Abstract

This empirical essay looked at the disaggregated and combined effects of renewable and fossil energy consumption on economic growth in Nigeria. Results based on a bounds test cointegration analysis suggest that conventional energy consumption is a strong driver of growth in the long run. A unit increase in conventional energy consumption will lead to a 0.056 unit increase in economic growth. This implies that fossil fuel energy consumption plays a significant role in improving the productivity of the economy and thereby driving economic growth, confirming the existence of the growth hypothesis in Nigeria. Contrary to a priori expectations, renewable energy consumption, although significant, has a negative coefficient both in the short and long run. The result shows that a unit increase in renewable energy use would reduce economic growth by 0.09 units in the long run. This implies that policy should be focused on a comprehensive examination of an optimal energy portfolio that can drive economic growth.

4.1 Introduction

This essay employs the ARDL approach to cointegration developed by Pesaran, Shin and Smith (2001) to analyse the impact of energy consumption (renewable and non-renewable) on economic growth. The economic importance of energy consumption and the environmental consequences and considerations have gained much attention globally. Theoretically, energy consumption contributes positively to economic activities (Stern and Cleveland, 2004). Disaggregating energy consumption into renewable and non-renewable components may cause this contribution to vary based on the energy source in consideration (Turner and Hanley, 2011; Chien and Hu, 2007; Hisnanick and Kymn, 1992). Particularly, the case for renewable energy is centred on the premise that renewable energy helps to increase universal access to energy supply, reduce environmental degradation and enhance sustainable development (UNCTAD, 2011). An added benefit is that access to modern, clean, affordable and reliable energy services promotes economic opportunities and fuels development (OFID, 2016).

However, the effect of renewable energy in the context of sustainable growth in developing countries (particularly African countries) is not very clear. More attention needs to be given to the nature of the relationship between energy consumption and economic growth, the process through which such relationship evolves during economic development, and the implications for development and poverty alleviation policies at different levels and stages of growth across countries.

Some studies appear to cast doubt on the positive effects of renewable energy options on growth, particularly in the context of developing countries which are well endowed in natural resources. Studies such as Dercon (2011), Resnick et al. (2012), Huberty et al. (2011), Dercon (2012) and Scott et al. (2013) have carefully examined the internalisation of environmental costs which may change patterns of growth and conclude that it is not very plausible that green growth will offer the rapid route out of poverty as it appears to promise, or even as rapid an exit with more conventional growth strategies. The clear indication here is the need for more studies, especially on Africa.

Although fossil fuel consumption comprising oil, coal, and natural gas have been proven to be major drivers of economic growth, they have also been viewed to have a negative influence on environmental quality (Newman et al., 1996). Recent economic research has focused on policies against global warming and is concerned with mitigation policies such as the international carbon tax and an international cap and trade tax set out to combat global warming in the U.S. and some other developed countries (Aldy et al., 2010; Taylor, 2015). Other studies have focused on the use of Renewable Energy Technologies (RETs) as a solution to climate change and global warming (Greine et al., 2012).

However, the literature on the processes through which economies can transit to renewable energy consumption is not clear, particularly for developing countries. Renewable energy consumption could be economically costly and may lead to domestic resistance among the poor. Hence it is said to be highly debatable that the process of transition can by itself produce the growth that most developing countries are seeking, as conventional energy may deliver a faster and easier route out of poverty (Resnick et al., 2012; Huberty et al., 2011; Dercon, 2012; Scott et al., 2013).

Thus, economic growth is a crucial concept that depends on an adequate combination of energy resources, clean and innovative production technologies and efficiency (Tugcu, 2013). In this context, based on the relationship between energy consumption and economic growth, where energy consumption is assumed to contribute positively to economic growth, disaggregating energy input into its components may cause this contribution to vary based on the energy source in consideration (Hisnanick and Kymn, 1992; Chien and Hu, 2007; Turner and Hunley, 2011). However, empirical research has negated the unique importance that could result from the disaggregating effects of energy consumption (renewable and non-renewable) on economic growth.

Rather, most studies have focused more on the causal direction between energy and growth (Ozturk, 2010; Lee and Chang, 2007; Odhiambo, 2009; Gollagari and Rena, 2013; Tsani, 2010; Ozturk et al., 2010). Given the context of the Nigerian economy, which is highly dependent on fossil energy consumption, empirical analysis that disaggregates energy input into its components may cause the contributions to vary based on the energy options in consideration. In this sense, by disaggregating energy consumption into fossil and renewable energy components, this study aims at investigating the combined and disaggregated effects of energy consumption on growth for insightful policy implications in Nigeria.

A unique contribution of this essay is that it distinguishes between the growth linkages of renewable and non-renewable energy by decomposing energy components. Based on the premise that renewable energy consumption can pave the way for growth, particularly in developing economies, a decomposed analysis of energy components was employed to evaluate the separate effects of energy components on growth. Since Nigeria faces large growth and development gaps despite the large deposits of renewable and conventional energy, the study further tested for the combined effect of renewable and non-renewable energy on economic growth. Finally it showed that instead of the various alternative hypotheses around energy and growth, there may be a unique combination present for different countries.

The study employed single-country data as the main focus is one country – Nigeria. Cross-country and panel studies are useful in understanding general and common trends in phenomena across countries or cross-sections. However, such studies can also fail to identify unique country effects and characteristics, which are only discoverable from country case studies. For instance Odhiambo (2009) shows that while cross-country data may be appropriate for several countries, it may be unable to explicitly address the possible biases induced by the presence of cross-country heterogeneity, which may lead to inconsistent and misleading estimates. Single-country data, on the other hand, maintains consistency and is suitable for situations where there are unique characteristics of the observation and phenomenon.

Hence, although Nigeria is a large exporter of oil it has peculiar characteristics which make it different from other oil exporters. For instance Nigeria has the largest population among OPEC member countries at 197.7 million, GDP at market price of $371,886 million, GDP per capita of $1,881, proven crude oil and natural gas reserves of 37,453 million barrels and 5,627 billion cubic metres respectively, oil demand of 425,900 barrel per day, and value of petroleum exports of $38,607 million (OPEC, 2018). This contrasts sharply with other energy producing and exporting countries such as Saudi Arabia, the United Arab Emirates and Angola. Saudi Arabia has a population of 32.5 million, which is less than one-fifth of Nigeria’s population, GDP at market price of $683,827 million, GDP per capita of $21,007, proven crude oil and natural gas reserves of 266,260 million barrels and 8,715 billion cubic metres respectively, oil demand of 324,200 barrel per day, and value of petroleum exports of $159,742 million. Angola has a population of 28.3 million, GDP at market price of $124,209 million, GDP per capita of $4,380, proven crude oil and natural gas reserves of 8,384 million barrels and 422 billion cubic metres respectively, oil demand of 115,500 barrel per day, and value of petroleum exports of $31,550 million.

According to the World Development Indicator of the World Bank, Nigeria has an energy use per capita of 763.3 kg of oil equivalent (in 2014) and poverty headcount ratio at $1.90 per day of 53.5% (in 2009) while Saudi Arabia has an energy use of 6,937 kg of oil equivalent (in 2014), and Angola has a poverty headcount ratio at $1.90 per day of 30.1% (in 2008). Given the differences among oil producing and exporting countries as the data above shows, a single country analysis is more suitable towards understanding Nigeria’s energy sector and growth.

The essay is structured as follows. The theoretical framework is discussed in Section 4.2. Section 4.3 discusses the data sources, and the model specification is discussed in Section 4.4. The estimation techniques and empirical analysis are presented in Section 4.5. The chapter ends with Section 4.6 where policy implications and conclusions are drawn.

4.2 Theoretical framework

Traditional economic growth theories postulate that energy plays no crucial role in the production process. However, recent models of economic growth and environment consider energy as an important factor of production in the production process (Stern, 2003; Thompson, 2006). Schurr (1983) noted that although energy intensity of production had fallen while both labour and total factor productivity were rising, this could not be explained solely on the basis of substitution of less expensive energy for more expensive labour (Jorgenson, 1984), but rather the production process is determined by capital stock, labour, energy and technical change (Toman and Jemelkova, 2002).

According to the growth model advanced by Romer (1990), long-run economic growth could be affected by forces that are mostly internal to the economic system, particularly those forces controlling the opportunities and motivations to create technological knowledge. Hence, in the long run the rate of economic growth, as measured by the growth rate of output per person, could depend on the growth rate of total factor productivity (TFP), which is in turn affected by the rate of technological progress. In this regard, energy consumption is believed to contribute positively to economic growth and this contribution is expected to be more pronounced when energy is disaggregated into various resources (Tugcu, 2013). It is expected that by disaggregating the energy options, this may cause the contribution to vary based on the energy source in consideration (Turner and Hanley, 2011; Chien and Hu, 2007; Hisnanick and Kymn, 1992).

4.3 Data source

The paper utilised yearly time series data over the period 1980–2016, sourced from the World Development Indicators (WDI) of the World Bank and U.S. Energy Information Administration (EIA). The choice of time frame was guided by data availability. The long-run economic growth impacts of energy consumption were established within an ARDL bounds testing approach by Pesaran et al. (2001) and Narayan and Narayan (2010) and is based on the following validations. First, the order of integration of the series does not matter as the ARDL does not enforce a restraining assumption that all the variables under study must be integrated of the same order, unlike other conventional cointegration techniques. Second, while other cointegration techniques are sensitive to the sample size, the ARDL approach is more suitable and appropriate for a small sample. Appropriate modification of the order of the ARDL technique can correct and provide unprejudiced estimates of the long-run model and valid t-statistics even when some of the regressors are endogenous.

The choice of variables is guided by the literature and availability of data. For the purpose of this study, Gross Domestic Product (GDP) in constant 2010 U.S. dollars is used as a proxy for economic growth. Based on the standard growth model (Kasperowicz, 2014; Chaudhry et al., 2012; Dagher and Yacoubian, 2012; Aqeel and Butt, 2001; Akinlo, 2008 and Romer, 1990), energy is decomposed into renewable and non-renewable energy sources and is included in order to measure the impact of individual energy components on domestic production and growth (Tugcu, 2013; Tugcu et al., 2012; Apergis and Payne, 2012; Soytas et al., 2007). Capital and labour are included in the model as control variables and are treated as separate inputs (Wang et al., 2011; Kasperowicz, 2014). Capital is measured by Gross Fixed Capital Formation, while labour is measured by secondary school enrolment (UCAN et al., 2014 and Zhao et al., 2016).

4.4 Model specification

Following the specific objective of this study, the study adopts a log-linear functional form of the Cobb–Douglas production function to explore the effect of energy consumption on economic growth. First the study estimated the standard growth model of the growth-energy nexus, which includes capital and labour, and compared this with a second growth model that disaggregated energy sources into renewable and non-renewable energy sources. The aggregated and disaggregated models are to show the combined effects of energy consumption on economic growth as well as the relative effects of the different components of energy consumption (conventional and renewable). From the literature, the standard growth model is specified as follows:

$$LNGDP_t = \alpha_0 + \alpha_1 LNEC_t + \alpha_2 LNK_t + \alpha_3 LNL_t + \varepsilon_t \qquad \text{... (4.1)}$$

$$LNGDP_t = \alpha_0 + \alpha_1 LNREC_t + \alpha_2 LNFEC_t + \alpha_3 LNK_t + \alpha_4 LNL_t + \varepsilon_t + \qquad \text{... (4.2)}$$

Where GDP stands for gross domestic product, RCE denotes the share of renewable energy consumption in total energy consumption, FEC denotes the share of fossil fuel energy consumption in total energy consumption, K represents physical capital and is proxied by gross fixed capital formation, and L is human capital measured by secondary school enrolment. GDP, K and L are logarithmically processed while REC and FEC are percentage values (K and L are control variables in the model). The long-run impact of energy consumption on economic growth is established within an ARDL bounds testing approach, popularised in Pesaran et al. (2001).

The ARDL representation of (4.3) and (4.4) below indicates that economic growth tends to be influenced and explained by its past values, the past values of all the explanatory variables as well as the change in the past values of all the variables in the model. Therefore, two models were specified, with one capturing the interaction between renewable and non-renewable energy and the other combining fossil and renewable energy.

$$\Delta LNGDP_t = \alpha_0 + \alpha_1 LNGDP_{t-1} + \alpha_2 LNREC_{t-1} + \alpha_3 LNFEC_{t-1} + \alpha_4 LNK_{t-1} + \alpha_5 LNL_{t-1} \sum_{t-1}^{n} \emptyset_1 \Delta LNGDP_{t-1} + \sum_{t-1}^{n} \emptyset_2 \Delta LNREC_{t-1} + \sum_{t-1}^{n} \emptyset_3 \Delta LNFEC_{t-1} + \sum_{t-1}^{n} \emptyset_4 \Delta LNK_{t-1} + \sum_{t-1}^{n} \emptyset_5 \Delta LNL_{t-1} + ECT_{t-1} + \varepsilon_t \quad \ldots (4.3)$$

$$\Delta LNGDP_t = \alpha_0 + \alpha_1 LNGDP_{t-1} + \alpha_2 LNEC_{t-1} + \alpha_3 LNK_{t-1} + \alpha_4 LNL_{t-1} + \sum_{t-1}^{n} \emptyset_1 \Delta LNGDP_{t-1} + \sum_{t-1}^{n} \emptyset_2 \Delta LNEC_{t-1} + \sum_{t-1}^{n} \emptyset_3 \Delta LNK_{t-1} + \sum_{t-1}^{n} \emptyset_4 \Delta LNL_{t-1} + ECT_{t-1} + \varepsilon_t \quad \ldots (4.4)$$

Where α_0 is a constant term, α_1 to α_5 are long-run coefficients, $\emptyset_1$ to $\emptyset_5$ stand for the short-run coefficients, Δ is the lag operator, and EC stands for primary energy consumption. All other variables are as defined above. The ECT is the error correction term, derived from residuals generated from the original functions. It shows the adjustment process of the short- to long-run equilibrium relationship between economic growth, energy consumption and other specified independent variables. As is standard, the coefficient of the ECM term is expected to be negative and also statistically significant for there to be short-run adjustment to long-run equilibrium. The error term, ε_t, is expected to be normally distributed (Gujarati, 2003). The model adopts the general to specific approach such that only variables with the best econometric properties and economic intuition are presented and discussed.

4.5 Estimation techniques and empirical analysis

4.5.1 Stationarity test

One of the pre-conditions for cointegration analysis is the test for unit root. A series is referred to as static if the mean, variance and auto covariance (at various lags) remain the same notwithstanding the point at which they are measured. That is, they are time-invariant (Gujarati, 2003). The bounds testing approach to cointegration requires variables to be stationary at levels or at most at first difference, giving it an advantage over other methods such as Johansen that require all variables to be stationary at first difference. For the purpose of the study, the test for stationarity in all the variables is done with two popular tests: the Augmented Dickey-Fuller (ADF) test and the Phillips-Perron (PP) test. The general form of the ADF test follows (4.5) below.

$$\Delta Y_t = \alpha + \beta_t + \gamma Y_{t-1} + \delta_1 \Delta Y_{t-i} + \cdots \ldots\ldots + \delta_{\rho-1} \Delta Y_{t-\rho+1} \varepsilon_t \qquad \ldots (4.5)$$

Where α is a constant, β is the coefficient on a time trend and ρ is the lag order of the autoregressive process.

The null hypothesis of the Augmented Dickey-Fuller t-test is

$\gamma = 0$ i.e. the data needs to be differenced to make it stationary)

Versus the alternative hypothesis of

$\gamma < 0$ i.e. the data is trend stationary and needs to be analysed by means of using a time trend in the regression model instead of differencing the data

The result of the ADF and PP tests are presented in Tables 4.1a and 4.1b.

Table 4.1a: Augmented Dickey-Fuller unit root tests

Variables	**ADF**				**Decision**
	Levels		**1st difference**		
	Constant	Intercept & trend	Constant	Intercept & trend	
LNGDP	-0.4029	-2.1649	-4.9042**	-5.2221***	I(1)
LNEPROD	-1.4796	-2.3348	-5.4709***	-5.4001***	I(1)
LNK	-0.7399	-1.9784	-4.5776	-9.4313***	I(1)
LNL	-1.1754	-3.6428**			I(0)
REC	-2.7236	-2.6978	-5.4004***	-5.2931***	I(1)
LNFEC	-2.4268	-2.5244	-5.1316***	-5.0688***	I(1)

Note: ***=1% sig. level; **=5% sig. level; *=10% sig. level

Table 4.1b: Phillips-Perron unit root tests

Variables	PP				Decision
	Levels		1st difference		
	Constant	Intercept & trend	Constant	Intercept & trend	
LNGDP	-0.7989	-2.1269	-4.9519**	-5.2732***	I(1)
LNEPROD	-1.4847	-2.4154	-5.4970***	-5.4822***	I(1)
LNK	-0.8980	-1.9240	-5.3816***	-6.0685***	I(1)
LNL	-3.0440**	-3.6731**			I(0)
REC	-2.7236	-2.6978	-5.5711***	-5.4362***	I(1)
LNFEC	-2.4268	-2.5244	-5.1316***	-5.0689***	I(1)

Note: ***=1% sig. level; **=5% sig. level; *=10% sig. level

As shown in Tables 4.1a and 4.1b, both tests show mixed results of the stationarity of the variables. Only labour is stationary at levels in both tests. However, all the other variables become stationary after first differencing. The differences in the order of integration among the variables provide strong justification for the bounds testing approach to cointegration.

However, it is expected that the presence of structural breaks could affect the relationship between energy consumption and economic growth (Kheraief et al., 2016). Structural changes that occurred in the economy over the years are likely to subject macroeconomic variables to structural breaks which can lead to huge forecasting errors and unreliability of the model in general (Gujarati, 2007). Therefore, because structural breaks in time series are of great importance for the stationary analysis, the study employed two of the commonly used structural break unit root methods – the Bai-Perron multiple breakpoint tests and Augmented Dickey-Fuller test statistic – to test for structural breaks in the regression.

The Bai-Perron test considers structural changes in the linear regression model. A major advantage of the test is that, unlike several structural break tests in the econometric literature, the break dates are treated as unknown variables that need to be estimated. Furthermore, it can estimate multiple break dates in the series (Bai and Perron, 1998). According to Xiong et al. (2016), the general model of the Bai-Perron test is as follows. It is assumed that there are m structural breaks in the linear regression with T time length.

$$y_t = x_i'\beta + z_i'\sigma_j + \mu_i \quad t = 1,2,\dots,T_1$$

$$y_t = x_i'\beta + z_i'\sigma_j + \mu_i \quad t = T_1 + 1, T_1 + 2, \dots, T_2$$

$$y_t = x_i'\beta + z_i'\sigma_j + \mu_i \quad t = T_m + 1, T_m + 2, \dots, T,$$

where y_t is the independent variable, x_i and z_i are dependent variables, β and σ are the coefficients variables, μ_i is the residual term, and T_1 is the time of the structural breaks.

The results of the structural break unit root tests are shown in Table 4.2 and Figures 4.1 to 4.3. Based on the results of the Bai-Perron test in Table 4.2, the null hypothesis that there are at least three structural breaks is accepted as the scaled F-statistics is higher than the critical values at the 1% significance level. The test further shows the break dates to be 2002, 2008 and 2014. The results of the ADF breakpoint test are shown in Figures 4.1 to 4.3. From the results, structural breaks were found in years 2001 and 2002. A sharp structural break was observed just after the period of the transition to civil rule in 2002. Another structural break was established in 2008 during the global economic meltdown, and another in 2014 which was the period leading to recession.

Table 4.2: Bai-Perron multiple breakpoint test

Break test	**F-stats.**	**Scaled-F-stats**	**Critical Values**
0 vs. 1 *	77.56294	232.6888	13.98
1 vs. 2 *	29.90979	89.72936	15.72
2 vs. 3 *	7.175640	21.52692	16.83
3 vs. 4	2.168193	6.504578	17.61
	Break dates	Sequential	Repartition
	1	2002	2002
	2	2008	2008
	3	2014	2014

Figure 4.1: ADF breakpoint test (GDP)

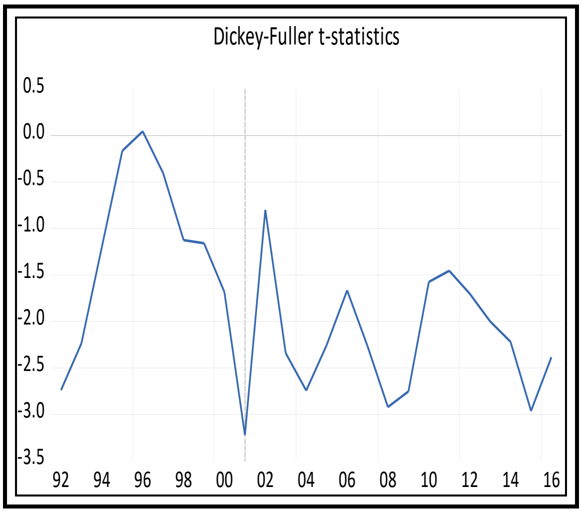


Figure 4.2: ADF breakpoint test (FEC)

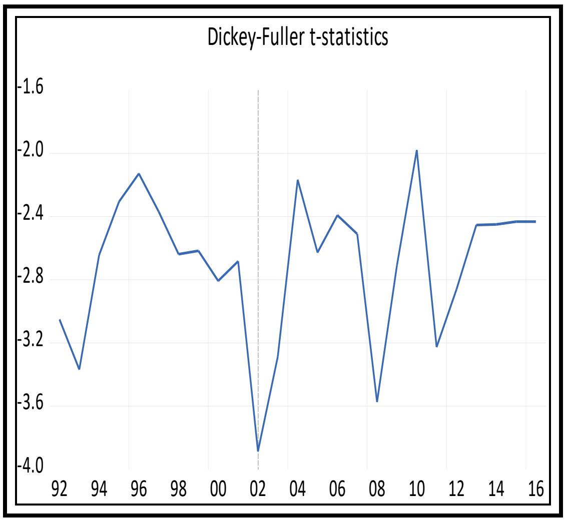
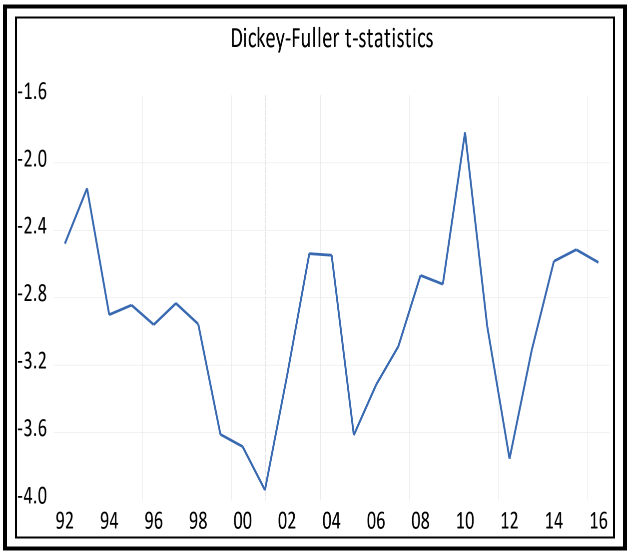


Figure 4.3: ADF breakpoint test REC



4.5.2 Cointegration analysis (bounds testing approach)

To determine the long-run co-integration relationship between growth and energy use in Nigeria, after observing the existence of structural changes, dummy variables were included in the regression and the unrestricted ECM was estimated with constant and no trend. The bound testing requires a test of the combined significance of the variables in the model or an F- (Wald test) under the null hypothesis that all variables in the model are jointly insignificant. Consequently, a statistically significant F-statistic is compared with the upper bounds of the critical values provided in Pesaran, Shin, and Smith (2001) for establishing a long-run relationship among stationary variables in the model. Thus, an F-statistic of 13.08 as shown in Table 4.3 for the disaggregated model and 11.12 for the aggregated model are sufficient for the strong rejection of the null of no long-run relationship between economic growth and the specified determinants in Nigeria as this exceeds even the 1 per cent critical value for the upper bounds test critical values in the disaggregated and aggregated models.

By including three dummy variables (dummy 1=2002, dummy 2=2008 and dummy 3=2014) to capture the structural breaks, the unrestricted constant and no trend model was estimated. Results for the disaggregated model showed that the dummies are weakly significant, implying that the transition to civilian regime partially affected economic growth. However, in the aggregated model, dummy 1 is highly significant and positive while dummies 2 and 3 are insignificant. From this result, particularly in the aggregated model, one can infer the possible effect of the transition to the civilian regime on economic growth. This is possible as government implemented significant policies during that period.

Table 4.3: ARDL bounds test

	Disaggregated Model		**Aggregated Model**	
Test Statistic	**Value**	**K**	**Value**	**K**
F-statistic	13. 08	7	11.12	6
Critical Value Bounds				
Significance	I(0) Bound	1(1) Bound	I(0) Bound	1(1) Bound
10%	2.03	3.13	2.12	3.23
5%	2.32	3.5	2.45	3.61
2.50%	2.6	3.84	2.75	3.99
1%	2.96	4.26	3.15	4.43

Table 4.4 presents the long-run elasticity estimates and shows that labour is a significant driver of growth in the long run in both the aggregated and disaggregated models. Capital is only significant in the aggregated model. In the disaggregated model, an increase in the share of fossil fuel energy increases economic growth significantly with a long-run elasticity coefficient of 0.056. This means that a unit increase in the share of fossil fuel energy leads to a 0.056 increase in economic growth, ceteris paribus. If the coefficients are interpreted as an elasticity, a one per cent increase in fossil fuel energy will lead to a 0.056 per cent increase in economic growth.

The share of renewable energy consumption appears to have a negative effect on economic growth in the long run. According to the results in Table 4.4, a unit increase in renewable energy consumption leads to a 0.093 decrease in economic growth, ceteris paribus. In terms of elasticity, a one per cent increase in renewable energy consumption will lead to a 0.093 per cent decrease in economic growth. This is however not puzzling given the hypothesis that for a developing country with large development gaps and slow growth in the midst of abundant non-renewable energy (which is already being utilised), the path to increased growth and rapid development cannot be by renewable energy alone. Given Nigeria’s fossil fuel dependent economy, it is understandable that renewable energy is less preferable and would have limited or no impact on economic growth. Indeed, using substantial renewable energy to boost growth and development at a rapid pace may be hinged on the continuous combination with non-renewable energy. It is also entirely plausible that the low utilisation of renewable energy in Nigeria at the moment could account for it not being a significant driver of growth.

The findings of this study are consistent with Hisnanick and Kymn (1992) and Tugcu (2013) and imply that policies that support and encourage the inclusion of the share of renewable energy consumption in the national grid of the country should be carefully implemented, if it is intended to benefit not only as a factor of production but also as a positive externality that strengthens the growth performance of the economy by its positive effects on sustainability.

Analysis of the aggregated model in Table 4.4 shows that combined energy consumption, capital and labour are significant drivers of growth in Nigeria. A unit increase in aggregate energy consumption will lead to a 1.34 unit increase in growth in the long run. Correspondingly, a one per cent increase in energy consumption will lead to a 1.34% increase in economic growth, other factors being constant. This result is in line with the growth hypothesis and supports the findings of Gozgor, Marco Lau and Lu (2018) for OECD countries, Lu (2017) for Taiwan, and Ogundipe and Apata (2013) and Muse (2014) for Nigeria. It implies that energy consumption is a significant driver of economic growth.

Table 4.4: Long-run model

Disaggregated Model					Aggregated Model				
Var.	**Coef.**	**Std.**	**T-stat**	**Prob.**	**Var.**	**Coef.**	**Std.**	**T-**	**Prob.**
FEC	0.056	0.018	3.056	0.007	**LNEC**	1.341	0.214	6.272	0.000
REC	-0.093	0.027	-3.399	0.003	**LNK**	0.158	0.066	2.373	0.031
LNK	0.109	0.169	0.645	0.527	**LNL**	0.7434	0.223	3.336	0.005
LNL	1.996	0.551	3.622	0.002	**DUMMY1**	0.2059	0.066	3.115	0.007
DUMMY1	0.172	0.092	1.879	0.077	**DUMMY2**	0.0827	0.057	1.440	0.170
DUMMY2	0.044	0.064	0.678	0.507	**DUMMY3**	0.091	0.048	1.891	0.078
DUMMY3	0.141	0.076	1.859	0.080	**C**	-0.1128	0.331	-0.341	0.737
C	1.984	0.358	5.544	0.0000					

Tables 4.5 and 4.6 present the parsimonious short-run error correction model estimates in the aggregated and disaggregated models. The error correction term, derived from the level form estimate of Equation 4.2, indicates the speed of adjustment from the short-run disequilibrium to long-run equilibrium relation of output and energy consumption in Nigeria. The ECM coefficients in both the aggregated and disaggregated models are negative, less than 1, and statistically significant at the 5 per cent level. For the disaggregated model, convergence to equilibrium state will occur at 12 per cent per year, while for the aggregated model, convergence to equilibrium state will occur at 29 per cent per year.

Table 4.5: Parsimonious short-run error correction model (disaggregated model)

Variables	**Coef.**	**Std. Error**	**T-Stat**	**Prob.**
LNGDP(-1)	0.879732	0.040686	21.62266	0.0000
REC	-0.011199	0.001953	-5.735039	0.0000
FEC	-0.006789	0.001483	-4.577548	0.0003
LNK	0.063186	0.022046	2.866052	0.0107
LNK(-1)	-0.050051	0.019752	-2.534033	0.0214
LNL	0.240038	0.046696	5.140437	0.0001
DUMMY1	0.020678	0.007958	2.598460	0.0187
DUMMY2	0.005232	0.007347	0.712072	0.4861
DUMMY3	0.016975	0.007670	2.213174	0.0409
C	1.984191	0.357871	5.544427	0.0000
ECM(-1)	-0.120268	0.009893	-12.15623	0.0000
R-squared = 0.99 F-Statistics = 21.013(0.0001)				

Variables	Coef.	Std. Error	T-Stat	Prob.
Adjusted R-squared = 0.99 S.E. of regression = 0.007 Sum of squared resid= 0.0008				

* p-value incompatible with t-Bounds distribution.

Table 4.6: Parsimonious short-run error correction model (aggregated model)

Variables	Coef.	Std. Error	T-Stat	Prob.
LNGDP(-1)	0.709445	0.067353	10.53331	0.0000
LNEPROD	0.247412	0.116192	2.129335	0.0502
LNEPROD(-1)	0.142351	0.107098	1.329160	0.2037
LNK	0.045799	0.027017	1.695180	0.1107
LNL	0.215994	0.066766	3.235092	0.0056
DUMMY1	0.038551	0.009759	3.950168	0.0013
DUMMY1(-1)	0.021279	0.010424	2.041310	0.0592
DUMMY2	0.009445	0.009321	1.013233	0.3270
DUMMY2(-1)	0.014587	0.009761	1.494413	0.1558
DUMMY3	0.014371	0.009045	1.588919	0.1329
DUMMY3(-1)	0.011915	0.009737	1.223699	0.2399
C	-0.112835	0.330782	-0.341115	0.07377
ECM(-1)	-0.29056	0.0278	-10.4402	0.0000
R-squared = 0.99 F-Statistics = 129.544(0.000) Adjusted R-squared = 0.99 S.E. of regression = 0.008 Sum of squared resid=0.009				

Several diagnostic tests are conducted to verify the stability and validity of the results. These include the Durbin-Watson and Breusch-Godfrey LM tests for serial correlation, Breusch-Pagan and ARCH tests for heteroscedasticity, Jarque–Bera test for normality, and cumulative sum (CUSUM) and cumulative sum of squares (CUSUMsQ) plots for stability. The results of the diagnostic tests are presented in Table 4.7.

The models contain some good econometric properties in terms of being stable, given the recursive estimates with the cumulative sum (CUSUM) and cumulative sum of squares (CUSUMsQ) plots. Both lie within the 5 per cent level of significance. Generally, CUSUM and CUSUMSQ plots are employed to check the stability of the long-run variables as well as the short-run movements for the ARDL-Error Correction Model as shown in Figures A.3 and A.7 in the Appendix. Thus, if the plots of the CUSUM and CUSUMSQ statistics lie within the critical bounds of five per cent level of significance, then the null hypothesis of all coefficients in the given regression are stable and therefore cannot be rejected.

The Durbin Watson (DW) statistic is a first order test for autocorrelation in the residuals of a statistical regression analysis, and results mostly lie between 0 and 4. A value of 2 means that there is no autocorrelation in the regression. Hence, the values of DW in the aggregated model (2.12) and disaggregated model (2.4) in Table 4.6 show the existence of no autocorrelation. The Breusch-Godfrey LM test statistics is a higher order serial correlation test and superior to the DW test. The errors are serially independent with the Breusch-Godfrey LM test statistic of 0.97 and a probability value of 0.99, leading to the acceptance of the null hypothesis of serial independence of errors.

The ARCH test for heteroscedasticity in the estimation confirms that the residuals are homoscedastic with an observed R-squared of 0.79 and its associated probability of 0.93. The probabilities of the ARCH test shows that the null hypothesis of heteroscedasticity is rejected. This is also confirmed by the Breusch-Pagan test. The statistic and the associated probability shows that the null hypothesis of heteroscedasticity is rejected. Lastly, the Jarque–Bera test for normality also shows that the residuals are normally distributed as the probability of the Jarque–Bera statistic are higher than the conventional 5% significance level. In effect, the diagnostics tests further strengthen and confirm the reliability and validity of the estimation results.

Table 4.7: Diagnostic statistics

	Disaggregated Model	**Aggregated Model**
Breusch-Godfrey LM test	0.97(0.35)	4.55(0.10)
Heteroscedasticity (Breusch-Pagan)	6.33(0.71)	13.96(0.24)
ARCH test	1.26(0.26)	0.46(0.52)
Normality (Jarque–Bera)	0.61 (0.73)	0.05(0.98)
Durbin-Watson	2.4	2.12
CUSUM at 5%	Stable	Stable
CUSUM Squared at 5%	Stable	Stable

Note: Probability values are in parenthesis.

4.6 Conclusion and policy implications

The paper evaluated the effects of energy consumption (renewable and non-renewable energy) on economic growth in Nigeria, using the ARDL bounds testing approach to cointegration by Pesaran et al. (2001). Two models were specified to determine the different growth effects of disaggregated (renewable and non-renewable) and aggregated energy consumption energy on growth.

In the disaggregated model, the analysis showed that there seems to be a statistically significant negative effect of renewable energy on economic growth in the long run. Although the case for renewable energy is centred on the premise that renewable energy helps to increase access to clean energy, for a developing country such as Nigeria with large fossil energy resources, renewable energy utilisation is still very low due to the limited development of renewable energy resources in the country. The results also showed that GDP responds positively to fossil fuel energy consumption in the short and long run. Thus, an increase in fossil fuel energy use will increase economic growth significantly with a long-run elasticity coefficient of 0.056. Similarly, in the aggregated model, the results appear to be statistically significant, implying that energy consumption drives growth in Nigeria. Hence, a unit increase in aggregate energy consumption will increase growth by 1.34 units in the long run. The error correction models (disaggregated and aggregated) indicate the speed or rate of adjustment from the short-run disequilibrium to long-run equilibrium relationship between energy consumption and economic growth in Nigeria. The coefficient of ECT in both models is negative and significant.

The result of this paper has implications for energy policy, especially as it relates to ensuring an adequate mix of conventional and renewable energy. The low development and high cost of renewable energy has not placed it on the same level as fossil fuel energy as a main driver of growth. While renewable energy is desirable due to its environmental effects, its impacts on economic growth need to be carefully examined before transitioning. Despite the clamour for renewable energy resources in fuelling economic growth, particularly for developing countries, for developing countries such as Nigeria, there may not be a clear-cut road map to achieving the desired growth considering the large deposit of fossil energy resources. Rather than a full transition to renewable energy, a combination of renewable and conventional energy may be more optimal for sustainable growth in Nigeria.

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CHAPTER FIVE
ENERGY, ECONOMIC GROWTH AND CO_2 EMISSIONS IN NIGERIA

5.0 Abstract

This essay examined the influence of economic growth on environmental degradation in Nigeria. The study employed yearly time series data from 1980-2016, using an ARDL bound testing approach to examine the long-run relationship between energy consumption, economic growth and CO_2 emissions in Nigeria. The results confirm a long-run relationship between the series and provide evidence in support of the EKC hypothesis in Nigeria. Estimates of the main parameters all have the expected signs. There is a positive sign between GDP and CO_2 emissions, while a negative sign is found for the square of GDP. This implies that GDP moves past the Environmental Kuznets Curve turning point. In addition, the estimates suggest that the environmental degradation effect of GDP growth is bigger than environmental quality enhancement effect.

5.1 Introduction

This essay highlights the recent global issues on climate change, and evaluates the effect of increased energy demand and supply for growth on the environment. The validity of the Environmental Kuznets Curve hypothesis is tested within the Nigerian context with a view to inferring policy implications for sustainable economic growth in Nigeria. This builds on the findings of the first paper. The first paper finds that fossil fuel energy consumption has a significant effect on economic growth. But the question remains of how this energy-intensive growth impacts the environment. This essay therefore extends the energy-growth nexus in the first paper to understand how the growth affects environmental quality, forming the energy-growth-environment triad.

It is well-known that energy use is an effective driver of economic growth (Stern, 2003). However, growth based on conventional energy has also been recognised to have a negative influence on the environment (Newman et al., 1996). This discovery has now shaped the centre of intense public policy debates resulting from recent developments in global warming and climate change. In line with this, this paper seeks to explore the effects of energy use on economic growth and the weight it exerts on resources from the environmental sustainability standpoint.

Over the years, emerging literature has presented contradictory interests on the environmental–growth relationship. While some have argued that depletion of the natural resource base places productive activities at high risk (Mishan, 1967;

Panayotou, 2003), several others have debated that the fastest route to environmental improvement is following the path of economic growth (Beckerman, 1992). These issues have been explored in the literature using the EKC hypothesis, which states that an inverted U-shaped relationship exists between economic growth and environmental degradation. However, various studies have found mixed results to support EKC for different countries. This could in part be due to lack of sufficient empirical evidence that has fully addressed how environmental quality changes at different stages of economic growth, or due to the restrictive econometric techniques that have been employed.

The EKC hypothesis has been the focus of discussion for the past two decades starting with the paper by Grossman and Krueger (1992) and followed by Shafik and Bandyopadhyay (1992), Agras (1995), Holtz-Eakin and Selden (1995), Selden and Song (1994), Tucker (1995), Suri and Chapman (1998) etc. The common strand that runs through all these models is the estimation of the quadratic, or log quadratic, relating some measure of environmental degradation such as ambient concentrations of SO_2, per capita emissions of CO_2, suspended particulate matter, lack of safe water, lack of urban sanitation, annual deforestation, municipal solid waste per capita, etc. with per capita income to test the inverted-U shape of the EKC hypothesis.

While making adjustments in the model by adding some explanatory variables such as investment shares, electricity tariffs, debt per capita, political rights, civil liberties and trade, most studies have shown that income has the most significant effect on environmental quality of all the explanatory variables (Agras and Chapman, 1999).

A point of similarity for these early models is the turning point of the quadratic relationship between income and pollution. That is the point at which countries will begin to demand better environmental quality. In the study by Shafik and Bandyopadhyay (1992) the turning point was consistent with Grossman and Krueger's (1992), at around $5,000 per capita income. Agras (1995) found an Asian turning point of $6,654, while Selden and Song (1994) consistently found turning points of over $8,500. Due to the current and projected distribution of per capita GDP and population, Selden and Song (1994) found that emissions would be increasing through the year at $2,100 for most pollutants.

Recent studies have estimated EKC models and found varying turning points. For example, Holtz-Eakin and Selden (1995) estimated the EKC function with CO_2 as the dependent variable and found a turning point at $35,428. Tucker (1995) analysed the changes in CO_2 versus income in yearly cross-sectional analyses within the time period 1971–1991 using a quadratic function, and found that the coefficients shift in a continuous pattern, such that the turning point is decreasing over time. Several other studies have contended the turning point and reasoned that the impact of threshold effect on various economies, particularly countries that are highly dependent on and are exporter of fossil energy fuels varies significantly (Stern, 2004).

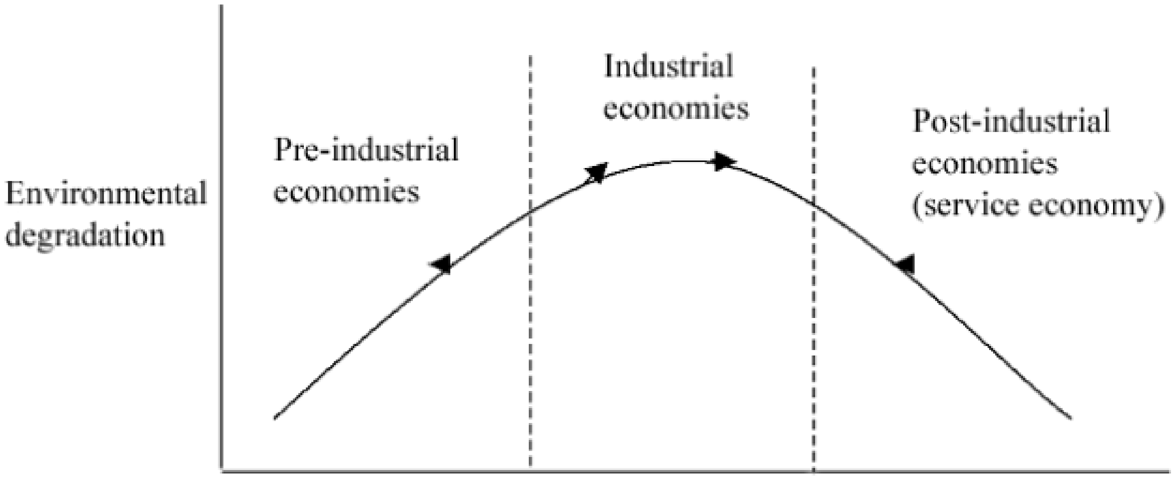
This study is different from other studies undertaken in Nigeria that have tested for the validity of EKC in Nigeria (Olusegun, 2009; Apkan and Chuku, 2011; Alege and Ogundipe, 2013). It went further to calculate the threshold point and analysed its impact on the economy. This analysis was carried out by employing an Autoregressive Distributed Lag (ARDL) to test the EKC validity on Nigeria. The study employed single-country data to cater for country-specific effects of energy consumption on economic growth and vice versa. According to Odhiambo (2009), cross-country data may not be able to explicitly address the potential bias introduced by the presence of cross-country heterogeneity, which may lead to inconsistent and misleading estimates. Single-country analysis therefore reveals unique country contexts.

This essay is structured accordingly. The theoretical framework is discussed in Section 5.2, the data source in Section 5.3 and the model specification in Section 5.4. The estimation techniques and empirical analysis are presented in Section 5.5 as the cointegration results are discussed. The chapter ends with Section 5.6 where policy implications and conclusions are drawn.

5.2 Theoretical framework

Grossman and Krueger (1992) were among the first studies to have used the EKC hypothesis to explain the link between the numerous indicators of environmental pollution and income. According to them, at the early stages of economic growth, pollution increases, but to a some certain level of income, which varies for different indicators and different countries, and after a while this relationship reverses, so that at very high income levels, economic growth tends to lead to environmental improvement (Panayotou, 2003). Figure 5.1 below depicts the various stages of the EKC.

Figure 5.1: Stages of economic-environmental development relationship



Source: Panayotou (2003)

The figure plots per capita income along the horizontal axis and the per capita index of environmental degradation on the vertical axis for any particular country. It portrays a relationship that takes the form of an inverted U-shaped curve, indicating that environmental pollution increases in the early stage of economic growth, and later on, per capita income starts to grow until it surpasses a certain level (i.e. turning point), where it starts to decrease as income increases.

According to Grossman and Krueger (1995), the fact that more economic activity unavoidably harms the environment is grounded on static assumptions of technology, tastes and environmental investments. So as incomes increases, the demand for improvements in environmental quality also increases, leading to increments in the natural resources available for investment (IBRD, 1992).

These views of the EKC hypothesis are presented using a quadratic function of the different levels of income, explaining the link between some measures of environmental degradation, *E*, and real per capita income. Hence, the standard EKC model is specified as follows.

$$\ln(E/P)_{it} = \alpha_i + \gamma_t + \beta_1 \ln(GDP/P)_{it} + \beta_2 (\ln(GDP/P))^2{}_{it} + \varepsilon_{it} \quad \ldots (5.1)$$

Where CO_2 emissions are denoted by E, P is population, In indicates natural logarithms, GDP is gross domestic product, GDP^2 is the square of GDP, α_0 is constant, and ε_t is a stochastic error term.

5.3 Data source

The paper utilised yearly time series data for the period 1980 to 2016. The data was sourced from the World Development Indicators (WDI) of the World Bank and the U.S. and Energy Information Administration (EIA). The choice of time period was guided by the availability of data. The long-run relationship between GDP and CO2 emission was established within an ARDL bounds testing approach advanced by Pesaran et al. (2001) and Narayan and Narayan (2010) and is based on the following validations. First, the order of integration of the series does not matter as, unlike other conventional cointegration techniques, the ARDL does not enforce a limiting assumption that every variables in the regression must be integrated of the one order. Secondly, even though other cointegration methods may be sensitive to the sample size, the ARDL approach is more appropriate and appropriate for a small sample. Appropriate modification of the order of ARDL technique can also correct and provide impartial estimates of the long-run model and valid t-statistics even when some of the regressors are endogenous.

The study is interested in the examining the impact of economic growth on environmental quality through the usage of energy consumption in Nigeria. Data was sourced from World Bank Development Indicators and the U.S. Energy Information Administration. CO_2 emissions (metric tons per capita), which stem from the burning of fossil fuels and the manufacture of cement, is used as a proxy for environmental quality. Although there are several indicators of environmental quality, CO_2 emissions are widely used in the literature due to the critical role of CO_2 emissions in climate change and global warming (Wolde, 2015; Apergis and Payne, 2010). GDP per capita is used as a measure of economic growth in this study. This measure is more appropriate because it indicates the average standard of living of the population which is a main driver of environmental quality (Agras and Chapman, 1999; Wolde, 2015). EC is also included in the model because it is a main driver of environmental quality. Recent evidence has shown that combustion of fossil fuel is the leading cause of man-made climate change, hence its inclusion in the mode l (Al-Mulali et al., 2014;

Schmanlensee et al., 2001). EC is measured as the total energy consumed from coal, natural gas, petroleum and other liquids, nuclear, renewable and others. The data are in constant 2010 U.S. dollars.

5.4 Model specification

Given the specific objective of this study, the study followed the empirical study of Stern (2004) and Shahbaz et al. (2013) who employed the EKC method with the simple standard functions of levels of income using logarithmic dependent and independent variables. The model is specified as follows:

$$LNCO_2PC_t = \alpha_0 + \alpha_1 LNEPROD_t + \alpha_2 LNGDPPC_t + \alpha_3 LNGDPPC_t^2 + \varepsilon_t \quad \ldots (5.2)$$

Where CO_2PC denotes emissions per capita, $EPROD$ stands for energy production, $GDPPC$ is gross domestic product per capita, and $GDPPC^2$ is the square of GDP per capita. All variables are transformed to log values in the estimation of Equation 5.4.

The turning point (threshold) of the quadratic relationship between economic activity and the quality of environment is obtained from the partial derivate of Equation 5.4 as below:

$$\frac{\partial LNCO_2PC}{\partial LNGDPPC} = \alpha_{2,t} + 2(\alpha_{3,t})LNGDPPC_t \quad \ldots (5.3)$$

The turning point where the GDP effect switches from negative to positive and vice versa occurs where the slope is zero. Thus if we substitute this point and solve for GDP we obtain

$$LNGDPPC_t = \frac{-\alpha_{2,t}}{2(\alpha_{3,t})} \quad \ldots (5.4)$$

Equation 5.4 also confirms the shape of the relationship whether concave ($\alpha_{3,t}$ is negative) or convex ($\alpha_{3,t}$ is positive).

The ARDL representation of Equation 5.3 below in natural log form indicates that CO_2 tends to be influenced and explained by its past values, the past values of all the explanatory variables as well as the change in the past values of all the variables in the model.

$$\Delta LNCO_2PC_t = \alpha_0 + \alpha_1 LNCO_{2t-1} + \alpha_2 LNEPROD_{t-1} + \alpha_3 LNGDPPC_{t-1} + \alpha_4 LNGDPPC_{t-1}^2 + \sum_{t-1}^{n} \emptyset_1 \Delta LNCO_{2t-1} + \sum_{t-1}^{n} \emptyset_2 \Delta LNEPROD_{t-1} + \sum_{t-1}^{n} \emptyset_3 \Delta LNGDPPC_{t-1} + \sum_{t-1}^{n} \emptyset_4 \Delta LNGDPPC_{t-1}^2 + ECT_{t-1} + \varepsilon_t \quad \ldots (5.5)$$

Where α_0 is a constant term, $\alpha_1$to α_4 are long-run coefficients, $\emptyset_1$ to $\emptyset_4$ stand for the short-run coefficients, Δ is the lag operator, and all other variables are as defined above. The ECT is the error correction term, derived from residuals generated from the original function (5.5). It shows the adjustment process of the short- to long-run equilibrium relationship between economic growth, energy utilisation and other specified independent variables in Nigeria. As is standard, the coefficient of the ECT term is expected to be negative and statistically significant for there to be short-run adjustment to long-run equilibrium. The error term ε_t is expected to be normally distributed where each individual error term is centred on zero with the same spread so that an error drawn has no effect on another error drawn, meaning that errors are serially independent. The data for this analysis was sourced from WDI of the World Bank and Energy Information Agency (IEA) over the period 1980 to 2016.

5.5 Estimation techniques and empirical analysis

5.5.1 Stationarity test

The bounds testing approach to cointegration requires variables to be stationary at levels or at most at first difference, giving it an advantage over other methods such as Johansen that require all variables to be stationary at first difference. In this paper, the test for stationarity in all the variables is done with two popular tests: the Augmented Dickey-Fuller (ADF) test, and the Phillips- Perron (PP) test. The form and mathematical expression of the ADF test has been described in Equation 4.5 in the previous chapter.

Table 5.1: Augmented Dickey-Fuller and Phillips-Perron unit root tests

Variables	ADF		PP		Decision
	Levels	**1st Diff**	**Levels**	**1st Diff**	
$LNCO_2PC$	-1.722758	-6.205237***	-1.778535	-6.248437***	I(1)
LNEPROD	-0.533434	-6.640630***	-0.580186	-10.83595***	I(1)
LNGDPPC	0.929579	-4.984696***	0.627129	-4.981328***	I(1)
$LNGDPPC^2$	0.953150	-4.971216***	0.645042	-4.967360***	I(1)
Intercept & Trend					
$LNCO_2PC$	-2.138497	-6.126482***	-2.200071	-6.170605***	I(1)
LNEPROD	-5.306692***		-5.101409***		I(0)
LNGDPPC	-3.006103	-5.099314***	-2.944547	-5.099314***	I(1)
$LNGDPPC^2$	-2.967649	-5.097776***	-2.907919	-5.097776***	I(1)

The results of the ADF and PP stationarity tests are presented in Table 5.1. The results show that all the variables are not stationary at levels for both tests. However, they become stationary after first differencing. When the intercept and trend are considered, only energy production is stationary at levels. However, all the other variables are stationary after first differencing. Both tests show mixed results of the stationarity of the variables. The differences in the order of integration among the variables provide strong justification for the bounds testing approach to cointegration.

5.5.2 Cointegration analysis (bounds testing approach)

To determine the cointegration link between energy consumption, economic growth and environmental degradation in Nigeria, the unrestricted error correction model is estimated and an ARDL (3, 0, 6, 4) is chosen based on the Akaike Information Criteria for the lag length selection as shown in Figure A5 (see appendix). Following this was the estimation of the restricted error correction model where the selection of the best economic and statistical properties is presented and discussed.

Table 5.2: ARDL bounds test

Test Statistic	**Value**	**K**
F-statistic	4.869	3
Critical Value Bounds		
Significance	I0 Bound	I1 Bound
10%	2.618	3.532
5%	3.164	4.194

1%	4.428	5.816

The test for long-run co-integration among the specified variables enables the identification of the short- and long-run relationship possibility under the bounds testing procedure. The error correction term, derived from the level form estimate of Equation 5.3, indicates the speed of adjustment of the short- to long-run equilibrium relation of growth and environment in Nigeria. Bounds testing requires a test of the combined significance of the variables in the model or an F- (Wald test) under the null hypothesis that all variables in the model are jointly insignificant. Consequently, a statistically significant F-statistic is compared with the upper bounds of the critical values provided in Pesaran et al. (2001) for establishing a long-run relationship among stationary variables in the model. An F-statistic of 4.87 as shown in Table 5.2 is sufficient for the strong rejection of the null hypothesis of no long-run relationship between real output and the specified determinants in Nigeria as this exceeds the 5 per cent critical value for the upper bounds test critical values.

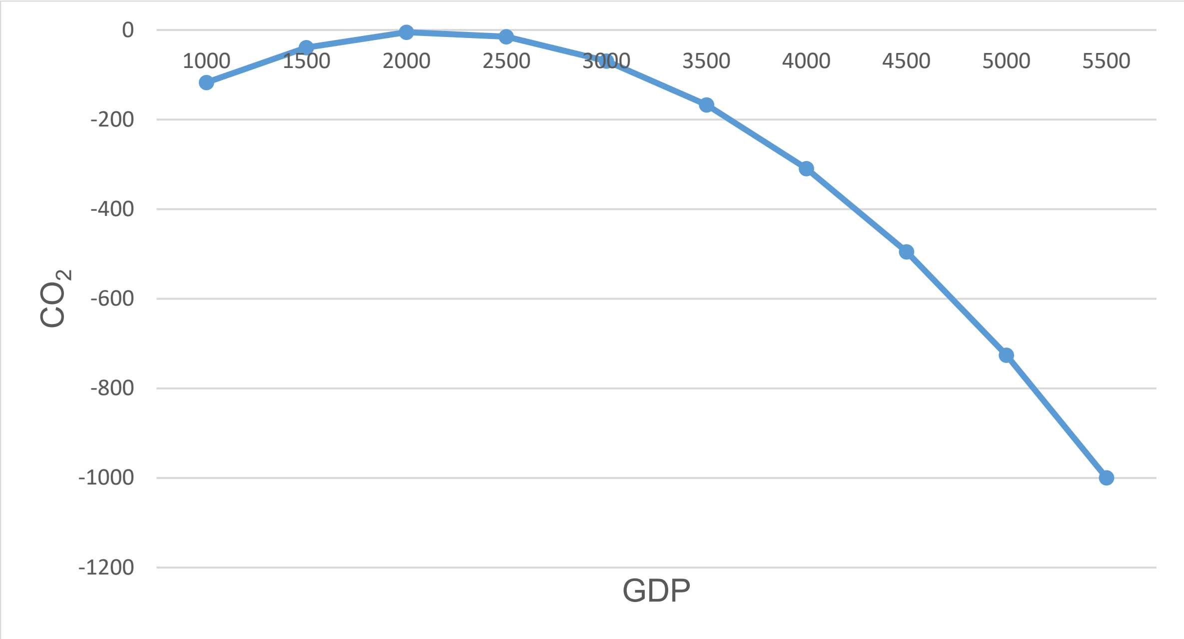
Table 5.3: Cointegration equation (long-run model)

Variable	Coef.	Std. Error	T-Statistics	Prob
LNEPROD	0.662	1.198	0.552	0.589
LNGDPPC	143.903	66.441	2.166	0.048
$LNGDPPC^2$	-21.999	10.221	-2.152	0.049
Turning Point (Threshold) Logged GDP per capita	3.27			
C	-238.6832	112.8222	-2.115569	0.0528
F-Statistic = 45.076 (0002) Durbin-Watson = 1.79 R-Squared = 0.834 Adjusted R-Squared= 0.724 Standard error of regression= 0.059				

Note: P-value in parenthesis

Table 5.3 shows estimates of the long-run relationship and confirms that most parameters have the expected signs. The results suggest a positive effect of GDP per capita on CO_2 emissions per capita, and a negative effect of the squared term of GDP per capita on CO_2 emissions per capita. This result confirms the EKC hypothesis for Nigeria. It implies that economic growth increases environmental pollution to a level after which environment quality improves with further growth. The coefficient of GDP per capita is large, and consistent with the results of other studies such as Agras and Chapman (1999) and Figueroa and Pasten (2009).

Figure 5.2: Plot of the EKC turning points



Sourced: Author's Computation

From the elasticity coefficients one can infer that the linear and non-linear terms for GDP per capita and square are 143.90 and -21.99 respectively, and both are highly significant. This provides evidence that supports an EKC hypothesis in Nigeria. Using Equation 5.4 above, the turning point where the GDP effect switches from positive to negative is equal to the logged GDP per capita of 3.27. The antilog of 3.27 is $1,862. This implies that at the early stages of development, growth leads to an increase in carbon emission up to the threshold GDP per capita of $1,862, after which the effect of GDP per capita on CO_2 switches to negative and economic growth leads to decline in CO_2 emissions at the later stage of development. This means that GDP growth will begin to lead to environmental improvement after it reaches a threshold point of $1,862. This result is consistent with those found by Panayiotou (2003), Song et al. (2008), Jalil and Mehmud (2009) for China, Halicioglu (2009) for Turkey, Fodha and Zaghdoud (2010) for Tunisia, Faridul and Muhammad (2012) for India, and Shahbaz et al. (2012) for Pakistan.

The linear term is bigger than the non-linear term, signifying that the environmental degradation effect of GDP growth is bigger than the environmental quality enhancement effect. This could mean that the Nigerian economy operates an intensive growth model where economic growth is associated with environmental degradation.

Table 5.4: ARDL short-run model

Variables	Coefficient	t-statistics	Prob.
C	-117.3314	-2.228844	0.0427
$LNCO_2PC(-1)$*	-0.491578	-3.102563	0.0078
LNEPROD**	0.325419	0.624702	0.5422
LNGDPPC(-1)	70.73997	2.216102	0.0438
LNGDPPC_2(-1)	-10.81458	-2.205711	0.0446
$D(LNCO_2PC(-1))$	0.300164	1.382947	0.1883
$D(LNCO_2PC(-2))$	0.225926	1.450219	0.1690
D(LNGDPPC)	78.53742	2.407002	0.0305
D(LNGDPPC(-1))	-111.6434	-3.459014	0.0038
D(LNGDPPC(-2))	68.24043	1.876238	0.0816
D(LNGDPPC(-3))	35.50579	1.000555	0.3340
D(LNGDPPC(-4))	-0.641076	-1.034630	0.3184
D(LNGDPPC(-5))	-2.104339	-4.330309	0.0007
D(LNGDPPC_2)	-12.13531	-2.382144	0.0319
D(LNGDPPC_2(-1))	17.20545	3.396034	0.0043
D(LNGDPPC_2(-2))	-10.88248	-1.892678	0.0793
D(LNGDPPC_2(-3))	-5.802355	-1.037552	0.3171
ECT(-1)	-0.491578	-5.594958	0.0001

Note: * P-value incompatible with t-Bounds distribution, ** Variable interpreted as Z = Z(-1) + D(Z).

Table 5.4 shows the parsimonious short-run estimates or the dynamic relationship between growth and the environment in the short run. The continuous switch in signs of both the linear and non-linear terms in the difference lagged terms confirm the dynamism in the relationship between the environment and economic activity. The coefficients of linear and non-linear terms of GDP per capita and GDP per capita squared also confirms the EKC relationship, but they are smaller than the long-run coefficient. The finding that the long-run income elasticity for CO_2 emissions is less than the short-run elasticity emphasises the long-run evidence in support of EKC in Nigeria (Narayan and Narayan, 2010). Impact of energy production is very small but insignificant in the short run. A 1% increase in energy consumption is expected to raise emissions by 0.32%. This is lower than the long-run result, and could mean the polluters obey the rules in the short run but tend to evade the laws in the long run.

The parameter which corrects for the error correction term (ECT-1) has the appropriate sign and is statistically significant. This suggests a 49 per cent adjustment speed of disequilibrium in the short-run to long-run equilibrium. The diagnostic tests show that the model is robust. The recursive estimates with the cumulative sum (CUSUM) plots lies within the acceptable 5 per cent level of significance. The errors are serially independent with the LM test statistic of 0.68 and a probability value of 0.86, leading to the acceptance of the null hypothesis of serial independence of errors. The errors are homoscedastic. Other diagnostic tests including the Jarque–Bera Normality and the residual plot, which confirm the reliability of the model, are presented in Table 5.2.

Table 5.5: Diagnostic statistics

Serial Correlation	0.6759(0.0.8576)
Heteroscedasticity (Breusch-Pagan)	0.6686(0.8079)
Normality	6.9132(0.0315)
Durbin-Watson	1.78
ARCH	0.9078(0.0.9117)
CUSUM at 5%	Stable
Adjusted R^2	0.7941

Values in parenthesis are *p*-values

S refers to the stability of the model

5.6 Conclusion and policy implications

The paper evaluated the link between economic growth and CO_2 emissions in Nigeria. The study employed annual time series data from 1980-2016, using an ARDL bound testing approach to examine the long-run relationship among energy consumption, economic growth and CO_2 emissions in Nigeria. Using the ARDL estimates we also calculated the threshold point for Nigeria for policy implications. The ADF unit root tests check for stationarity, and the ARDL approach to cointegration was employed for the EKC relation. The results confirm a long-run relationship among the series and provide evidence in support of EKC in Nigeria.

This result confirms the EKC hypothesis for Nigeria. Specifically, as economic growth increases it worsens the quality of the environment up to a level where improvements in environmental quality begin to occur with further growth. Overall results show that the net effect on the environment may be negative as the environmental degradation effect of growth is larger than the environmental quality enhancement effect. A unique feature of this paper is the computation of the threshold effect. The calculated threshold point of GDP per capita of $1,862 implies that at the early stages of development, economic growth leads to an increase in carbon emission up to a threshold of $1,862 after which the effect of GDP per capita on CO_2 switches to negative and economic growth leads to a decline in CO_2 emissions at the later stage of development.

The policy implication of this study is that efforts to improve economic development in Nigeria would lead to environmental degradation up to the level where the GDP per capita is $1,862 after which environmental quality begins to improve. Thus, during the early stage of economic development, government should be wary of the environmental impacts of its economic development efforts. However, these environmental concerns would not last as they would improve with more economic development.

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CHAPTER SIX

AN ECONOMIC COST BENEFIT ANALYSIS OF ENERGY SOURCES IN NIGERIA

6.0 Abstract

This essay investigates the economic viability of energy options in Nigeria for financing an optimal energy portfolio. Different methods, including the cost benefit analysis, life cycle cost analysis and the cost effectiveness analysis, were employed for the assessment of seven different technologies (gas, solar, wind, large hydropower, biomass, diesel-powered and coal). Based on these method, the benefit cost ratio and the levelised cost were used as the criteria for choosing the most economically feasible energy options to be included in the energy portfolio, this was followed with sensitivity analysis. The results clearly revealed that when the environmental effects are taken into consideration from a cost and benefit point of view, hydro, wind, solar and gas sources are the most competitive and viable options amongst the available energy sources. This has implications for rethinking strategies for energy portfolio options. An obvious portfolio from the analysis would have to include hydro, wind, solar and gas. The findings of this essay have pertinent policy implications and suggest the need for a more integrated energy and growth policy.

6.1 Introduction

The third paper examines the viability of alternative energy sources in Nigeria. Given the importance of energy consumption for economic growth as shown in paper one, and the role of fossil fuel-intensive economic growth on the environment in Nigeria as the results of paper two show, there is need for Nigeria to develop an optimal mix of energy resources to promote economic growth and simultaneously protect the environment. This requires an appropriate combination of conventional and renewable energy resources while considering the cost and benefits of each energy option. Drawing from the findings of the first two papers, this is the main focus of this paper.

It has been argued that countries must embrace all sources of energy that are environmentally friendly in order to fuel growth. However, the literature for transiting to renewable energy is not yet clear and proven, especially when a developing country in dire need of energy has potential sources of fossil-based fuel. There are costs and benefits from adopting various energy options and these must be balanced with economic needs to result in an economically optimal energy mix (Huberty et al., 2011; Dercon, 2012; Scott, 2013; Resnick et al., 2012). This essay focuses on the costs and benefits of feasible energy options for economic growth and development in Nigeria.

Recent concerns on global issues, depleting fossil fuels and international legislation such as the Kyoto Protocol have increased pressure on all governments to reduce CO_2 emissions and generate clean energy from sustainable sources. Despite the commitment to environmental quality by the Nigerian government, access to a clean, reliable and affordable energy supply remains a challenge in Nigeria despite the abundance of natural resources. The contribution of renewables to the national grid still remains very low, at about 1 per cent based on the Energy Commission of Nigeria report (ECN, 2014). Efforts to speed up the transition process to provide an adequate energy supply to meet the current and future demand of Nigerian citizens have yielded few results. To this moment, there is no clear vision in terms of policies and strategies put in place that defines what the path for Nigeria's future energy generation should be, nor is there a concept of how to align such visions and policies with the country's sustainable development plans. These issues reinforce the need for this study.

In Nigeria, on-grid electricity power generation capacity is dominated by natural gas power stations (86 per cent of capacity) and three large hydropower plants (14 per cent of capacity). Off-grid generation occurs almost entirely via costly and polluting diesel and petrol generators, of which there are an estimated 60 million in the country (NDC, 2016). Electricity consumption per capita in Nigeria is far below its peers compared to the per capita electricity consumption of other sub-Saharan countries such as Ghana, South Africa, Kenya and Egypt.

In the 2017 Economic Recovery Growth Plan (ERGP) short-term goals, the government reiterates the support for the inclusion of renewable energies in the current energy mix (Ministry of Budget and National Planning, 2017). However, these goals are somehow detached from any mid-term and future energy mix plan that takes into account the relative costs and benefits of the different options for economic recovery of the power sector (Roche, Ude and Donald-Ofoegbu, 2017). Studies on the economic viability of the different energy options for an optimal energy portfolio mix in Nigeria are rare.

Furthermore, although renewable energy sources are seen as means to increase energy supply, provide a better and cleaner environment, and generate higher income and sustainable economic growth, it is also seen as not only economically costly but also could lead to huge burden for the poor (Resnick and Thurlow, 2013; Huberty et al., 2011; Dercon, 2012; Scott et al., 2013). Nonetheless, the extent to which renewable energy can enhance energy access for sustainable growth in Nigeria is not adequately exploited. Although a number of studies examine the cost and benefit of specific energy sources (Thiam, 2010; Gwavuya et al., 2012), few studies extend this analysis to multiple energy sources to come up with a portfolio mix of energy options.

Energy is crucial for economic growth and this was empirically examined and established in Chapter 4 of this thesis. Nigeria being an energy producer, the Nigerian economy is partly dependent on fossil fuel energy production and export, and this accounts for a major proportion of economic growth, foreign exchange and government revenue. However, the excessive consumption of energy, especially fossil fuel, emits CO_2 emissions which are detrimental to the environment and the main cause of climate change and global warming. As energy consumption drives economic growth, both have considerable impacts on the environment as was shown through the examination of the EKC hypothesis in Chapter 5 of this thesis. From the analysis, the validity of the EKC hypothesis in Nigeria is established, implying that economic growth leads to environmental degradation up to a certain point after which it begin to lead to an improvement in environmental quality.

With this in mind, the optimal mix of energy sources is critical for ensuring that energy contributes to economic growth without degrading the environment, and this is the focus of Chapter 6. The chapter evaluates the costs and benefits of various energy sources, including conventional and renewable energy sources.

Although the share of renewable energy consumption in total energy consumption was about 87.3% in 2017, this does not mean that Nigeria has made progress in renewable energy development as the structure of renewable energy is dominated by biomass resources such as firewood, crop stalks, etc. Given the current global climate problem, there is a need for fossil-fuel dependent countries such as Nigeria to consider gradual transitioning to clean and renewable energy. More challenging is the fact that although there are various options for energy production, the choices for the selection of energy options for an optimal energy supply remain a huge challenge. This to some extent depends on the viability of the alternative energy sources. According to Turkson and Wohlgemuth (2001) and ECA (2004), the ability to provide a financially feasible, reliable and efficient modern energy option is crucial for development.

While there have been improvements in renewable energy viability and adoption in developed countries such as Germany, Sweden, Denmark and Kenya, Nigeria is still lagging behind. This is partly attributable to the lack of adequate technical analysis of the cost and viability of alternative energy sources in Nigeria, and this is the gap that this study fills. Several studies abound on the viability of alternative energy sources in the literature (Lai and Mcculloch, 2017; IRENA, 2018; Parrado et al., 2015, Shrimali et al., 2016; Kost et al., 2018), but the levelised costs of different energy sources vary across countries due to differences in energy potential, technical know-how and socio-economic conditions. This paper builds on the existing literature by evaluating the viability of alternative energy sources in Nigeria focusing on their relative costs and supply efficiencies. The findings of the study will be important for determining the energy portfolio mix for Nigeria and serve as a guide for enhancing energy access in the long term.

The essay is structured as follows: Section 6.2 provides the sources of data, followed by the theoretical framework in 6.3. The estimation techniques along with the costs and benefits analysis are discussed in section 6.4 and 6.5 respectively. Section 6.6 discusses the Life cycle cost analysis, followed by cost effectiveness analysis in section 6.7. Sensitivity analysis and the empirical analysis are presented in sections 6.8 and 6.9, and Section 6.10 concludes the chapter with policy implications.

6.2 Sources of data

Data was sourced from the National Electricity Regulatory Commission (NERC), Energy Commission of Nigeria (ECN) and private companies. The costs related to climate change, particularly CO_2 emissions, are based on widely accepted U.S. Environmental Protection Agency (EPA)-defined greenhouse gas (GHG) direct emission profiles of different generation sources. Therefore, this study borrows from the work done by Kolhe et al. (2002), Lutz et al. (2006) and Thiam (2010). Kolhe et al. (2002) investigated the economic viability of a stand-alone solar photovoltaic system in comparison with a diesel-powered system in India. Lutz et al. (2006) evaluated the life-cycle cost analysis of energy efficiency design options for residential furnaces and boilers. Thiam (2010) investigated the feasibility analysis of off-grid stand-alone renewable technology generation system for some remote rural areas in Senegal using a life cycle cost analysis.

6.3 Theoretical framework

The effect of energy supply shortages, global warming, and climate change have contributed to the surge in the usage of alternative energy options. The global economy is affected by increases in prices of the raw tools and machines of renewable energy options and is in turn affected by the continuous uncertainty of fuel-based energy prices. For these reasons, a mix of renewable energy and conventional energy has a fundamental role in expanding universal access to energy supplies, providing new job business opportunities, reducing external energy reliance and, at the same time, contributing to the reduction of greenhouse gas emissions (Fernandes et al., 2011).

However, Schmalensee (2012) opined that there is very little validation of the danger to economic growth in the short or medium term from the usage of natural energy resources or unrestrained environmental pollution, as it is neither clear nor established that a switch to a green economy can by itself produce the expected growth most countries are pursuing (Huberty et al., 2011). Hence, for developing economies growth based on a conventional energy supply may deliver a speedier route out of energy scarcity and poverty (Dercon, 2012). Janicke (2012) supported this argument that giving up on growth is neither a necessary solution nor a way to tackle the environmental issues since there is no guarantee that green growth will provide a rapid and enhanced path out of poverty, as there could be a less rapid exit with more conventional growth policies (Scott et al., 2013).

To achieve an optimal energy mix, it has been argued that countries must embrace all sources of energy that are environmentally friendly to fuel growth. However, the literature for transiting to renewable energy is not yet clear and proven as it is said not only to be economically expensive but also could lead to a huge burden for the poor. Hence it is highly debatable that the process can by itself produce the growth that most countries are pursuing. This is particularly so for developing countries in the sub-Saharan region, as conventional growth may deliver a speedier route out of poverty (Resnick et al., 2012; Huberty et al., 2011; Dercon, 2012; Scott, 2013). Thus, this study sets out to empirically assess the optimal energy mix for Nigeria by employing a Cost-Benefit Analysis (CBA), Life Cycle Cost Analysis, and Cost Effectiveness Analysis (CEA). It employed the levelised cost analysis and the benefit cost ratio as criteria to select the most feasible energy options for an optimal energy mix in Nigeria.

6.4 Estimation techniques

To analyse the economic viability of alternative energy resources in Nigeria, the study uses a number of methods to assess energy options. These include CBA and Cost CEA, LCA, Levelised Cost Analysis (LCA), and Benefit Cost Ratio (BCR). In addition, to account for the risks and uncertainty in energy investments, a sensitivity analysis was employed.

6.5 Cost benefit analysis (CBA)

CBA is the process of ranking, comparing, appraising or assessing a project or a proposal (Boardman et al., 2006). This process involves measuring the total costs (implicit and explicit) and comparing them with the total benefits of one or more projects or investments. Broadly, it ranks policy decisions from a financial and economic point of view, considering the consequences or social costs and benefits of alternative projects or investments (Boardman et al., 2006). Costs and benefits of the different projects are then measured and compared against each other in order to produce criteria for decision-making (Hosking and du Preez, 2004).

A typical cost benefit analysis for energy projects consist of four basic elements: time, costs, benefits and the social discount rate. The costs and benefits of the different projects are then measured and compared against each other in order to generate criteria for decision-making (Hosking and du Preez, 2004). Some such decision-making criteria often used in literature are:

1) Net Present Value (NPV);
2) Benefit-Cost Ratio (BCR);
3) Internal Rate of Return (IRR).

CBA is also used to assess the viability of different investments considering the future realisation and timing of costs and benefits. The theoretical foundation defines benefits as increases in human well-being (utility) and costs as decreases in human well-being (OECD, 2006). The aggregation rule in CBA necessitates that higher weights be apportioned to benefits and costs accruing to the disadvantaged or low income groups. The rationale for this rule is that marginal utilities of income vary. Therefore, to appraise capital investment projects, cash flows are discounted into forthcoming benefits and costs, known as present values (Boardman et al., 2006).

The success of CBA is that the results from the analysis serve as tools for helping policy makers to determine whether a project should be embarked on or not and which allocation of resources is optimal. When calculating CBA, the main focus is on monetary values for the assessment of the net effect of social benefits and costs (ECA, 2010). Therefore, in evaluating the costs and benefits associated with any project, it is imperative to include all the possible benefits and costs of flexible investment strategies.

According to the literature, CBA involves four stages. First, an analysis of carefully chosen technologies is executed which allows for the identification and determination of economic and technical factors. Second, the quantification of energy produced by the different energy options is determined. Third, the total costs and benefits of various options are carried out. Finally, the environmental costs are incorporated into the economic evaluation to allow for the determination of the levelised energy cost. These methods allowed for the comparison of the different technology options in Nigeria.

6.5.1 Costs and benefits identification, quantification and monetisation

In identifying costs in CBA, only the impacts that affect the utility of individual projects are included, while the impacts that do not have any value to human beings are omitted (Boardman et al., 2006). Relevant costs and benefits are measured in monetary terms, and include investment costs (residual value of fixed assets such as land and buildings where the technology will be sited), operating costs (raw materials, labour, and maintenance of supporting equipment) for the entire expected economic life of the project. Identified benefits that will be gained may include financial and economic benefits such as revenue generated from the sale of power, financial value for displacing carbon emission by a kilovolt of solar energy, and energy security value.

6.5.2 Valuation and monetisation of benefits

In most cases indirect benefits from REs cannot be easily quantified in monetary terms, but it is important that they are included in the analysis as they are essential for a meaningful analysis. Examples of such indirect benefits may include reductions in carbon emissions and global warming and energy security. The economic and environmental benefits (positive externalities) of renewable energy options could include the lessening of carbon dioxide emissions and the amount of conventional or other non-renewable energy sources saved.

Table 6.1: Costs and benefits associated with renewable technologies

Costs	**Benefits**
Pre-development cost	Financial and economic benefits
Investment costs	Environmental benefits
Operating costs - Maintenance costs - Fuel costs - Waste costs	Security of supply
Decommissioning costs	Employment benefits
Others	Other benefits

6.5.3 Net Present Value (NPV)

The net present value (NPV) is a widely known method for discounting future costs and benefits into present values. It assumes that members of a particular population give up present consumption to invest in a project that over time is expected to yield a return. To aggregate the impacts that occur in each year of the project, this step is necessary as there is an opportunity cost to resources and people prefer current consumption (consumption today is worth more than future consumption unless one is compensated for deferring it), so future money has a lower value. Through discounting, it can be assessed if the project is likely to earn a greater return than if the resources had been alternatively used. All cash flows occurring in year *t* are discounted to their present value by dividing by (1 + s) – see Equation 6.1 (Boardman et al., 2006):

$$NPV = \sum_{t=0}^{n} \frac{NB_t}{(1+s)^t} = \sum_{t=0}^{n} \frac{B_t}{(1+s)^t} - \sum_{t=0}^{n} \frac{C_t}{(1+s)^t}$$ **...** (6.1)

Where t stands for the time of the cash flow, s stands for social discount rate, NB_t is the net cash flow (the total amount of cash, inflow minus outflow) at time t, B_t is the benefits at time t and C_t is the costs at time t.

6.6 Life-cycle cost analysis of energy options

The life cycle cost of the various energy options include the initial investment costs (C_c), costs incurred during operating and maintenance (C_m), replacement cost (C_R), fuel costs (C_f), and environmental cost (C_e). This is specified as:

$$LCC = C_c + C_m + C_r + C_f + C_e$$ … (6.2)

Capital costs (C_c) are the sum of all costs associated with the purchase of equipment, including engineering costs, and all costs related to installation.

6.6.1 Operating and maintenance costs

This generally includes taxes, insurance and all recurring costs. It is specified as:

$$C_m = AnnC_m \left\{ \left(\frac{1+i}{r-i} \right) \times \left[1 - \left(\frac{1+i}{1+r} \right)^N \right] \right\} \quad \text{… (6.3)}$$

Where i denotes the interest rate, r is the discount rate, $AnnC_m$ corresponds to annual operating and maintenance costs and N represents the number of years of a project in consideration.

6.6.2 Replacement costs

This signifies the total costs incurred during the replacement of certain system apparatuses that have a lifetime shorter than that of the project. They include replacement costs covering the depreciation of certain devices such as batteries. Battering replacement cost is equal to the number of batteries replaced (v) over the system lifetime expressed as follows:

$$C_R = \sum_{i=1}^{v} \left\{ item\cos ts \left(\frac{1+i}{1+r} \right)^{N_T} \right\} \quad \text{… (6.4)}$$

Where V is the number of battery replacements, N is the battery life span, I is the inflation rate and R is the discount rate.

6.6.3 Fuel cost

This represents costs incurred in the use of fossil fuels for the operation of conventional technologies. In the case of renewable technologies, these costs are zero.

$$Cf = AnnuCf\{(\frac{1+pf}{r-pf})*[1-(\frac{1+pf}{1+r})^N]\} \quad \text{… (6.5)}$$

Where Pf represents the fossil fuel price, r stands for discount rate and other variables are as defined above.

6.6.4 Environmental cost

These are the costs of external effects generated via the consumption of conventional energy options. In this study, coal and gas have a higher environmental cost due to their greenhouse gas (GHG) emissions, which are pollutants to the atmosphere. Hence any analysis of energy alternatives must consider the environmental costs. Gas and coal, which are non-renewable energy resources, are less socially desirable. Renewable energy sources that include wind, solar, biomass and hydro that do not emit GHGs and are more environmentally friendly, are more socially desirable.

However, there are also pollutions from photovoltaic production, which may lead to the disruption of biodiversity especially fragile semi-arid land ecosystems, shortages of land space due to competition with crops and plants, competition for fresh water, changes in the landscape, and albedo decreases. Similarly, the issue of food insecurity, changes in wildlife habitat, and competition with animals and crops for irrigated water due to the need to acquire land for renewable technologies need to be considered.

6.7 Cost effectiveness analysis

Cost effectiveness analysis (CEA) is an economic analysis which relates the relative expenditure (cost) and output effectiveness of two or more energy options (Dimakis et al., 2008). CEA is usually employed to give better informed choices when various energy options are assessed to provide a foundation for the comparison of the important changes in the costs and output on which such decisions are to be made (Yao, 1992). In such analyses, costs are usually calculated as the direct financial or economic costs of executing a proposed method, with effectiveness defined in terms of some physical measure of environmental result (RPA, 2004). The measure of effectiveness is selected to reveal the objective set as closely as possible. Therefore, costs and output estimates are measured over the same time period and with the same unit of measurement. That is, outputs and costs may be estimated either on an average annual basis or on a total output and cost basis (Robinson et al., 1995). In literature, this is mostly done by calculating the levelised costs of energy output.

6.7.1 Levelised cost of energy supply

To compare energy options, it is important to identify effective and ineffective options through levelised costs. This technique offers a good valuation of the cost of energy

(IEA, 2005). In this case, the method ensures that a power plant is continuously substituted to produce incremental electricity to meet new increasing energy demand. The values of expenditures are discounted to their present values in a stated base year by applying a discount rate. The levelised lifetime cost per kWh of electricity generated is the ratio of total lifetime expenses to total expected outputs, expressed in present value. According to Weisser (2003) and IEA (2005), the levelised-cost of energy options is arrived at by dividing the total life cycle cost by the quantity of energy output provided. From the formula provided by IEA (2005), LEC is as follows:

$$LEC = \frac{TLCC}{QEO} = \frac{TLCC}{\frac{(KWh.production)_j}{(1+r)N}} \quad \text{… (6.6)}$$

Where LEC stands for the levelised costs, $TLCC$ is the total life cycle cost, QEO stands for the expected output and other variables are as defined.

6.7.2 Capacity factor

Capacity factor is the ratio of actual electricity output generated during a period to the electricity that could have been generated over that same period with operation at full design output power. This is a measure of the efficiency and operating performance of a generating system. The capacity factor is a useful indicator for selection of the most efficient energy technology from an array of energy resources. For conventional energy resources, their operating efficiencies are very high from energy generated by these resources and almost at full capacity compared to renewable energy resources, where capacity factors range from 20%-37%. The poor efficiency of these resources is mainly due to their intermittent nature as a result of the high seasonal and solar cycle dependence.

6.8 Sensitivity analysis

Sensitivity analysis investigates the robustness of net benefit estimates, and how sensitive the predictions are to changes. It is essential in any analysis because the longer the life of the project, the more uncertain things become as assumptions are projected further out in time. It should include, for instance, forecast of demand dynamics, unexpected occurrences and shocks, variations in fees, taxes and tariffs, and forecasts of cost dynamics. According to Boardman et al. (2006), a Monte Carlo analysis of expected net benefits may be employed as it considers all the available information about the values of parameters. In a way to guarantee that the discount rate used in this study is suitable and not solely accountable for the outcome of the project analysis, it is of paramount importance to check the responsiveness of the viability of the technologies to changes in the base assumptions. The aim of this procedure is to find a balance between the relative uncertainty and the relative magnitude of contingencies on the overall results by modelling the low and high case scenarios on the values of levelised costs and benefits cost ratio.

6.9 Empirical analysis

This section focuses on the empirical investigation carried out in achieving the objectives of the study. The various estimation techniques discussed above were employed to assess the most feasible energy options for an optimal energy mix in Nigeria.

Table 6.2: Technical and economic features of selected energy technologies

Parameters	**Unit**	**Gas**	**PV. Tech**	**Large-hydro**	**Wind Tech**	**Diesel-Powered**	**Biomass**	Coal
Installed capacity	MW	250	5	300	10	0,25	10	250
Capital cost	$/kW	1200	1190	1800	1660	6500	2900	2730
Technical lifetime	Year	20	20	40	20	20	20	40
Capacity factor	%	80	19	65	32	60	60	70
Fixed O & M	$/kW/yr	15.50	30	13.77	18.50	15.00	53.50	32.00
Variable O & M	$/kW/yr	0.006	0.06	0.001	1.480	0.015	0.0010	0.001
Fuel cost (HHV)	$/MWh	3.30	0	0	0	18	4.00	5.10
Construction time	Year	5	2	5	2	0	2	5
Exchange rate	Naira	305	305	305	305	305	305	305
Real WACC (NERC)	%	11	11	11	11	11	11	11
Local inflation	%	7	7	7	7	7	7	7

Source: Roche et al. (2017) and NERC (2015)

Table 6.2 presents the technical and economical features of selected energy options. The table contains all the data used in this essay, which are sourced from Roche et al. (2017) and NERC (2015). It gives the capacity factors, the local inflation rate, and the real WACC. Generally, most energy options operate at an average capacity factor within 12-80% (Kolhe et al., 2002) as seen in the table. The inflation rate was the prevailing rate at the period of investment and is given by the Central Bank of Nigeria (CBN). The weighted average cost of capital (WACC) of 11 per cent is the overall cost of capital for all funding sources at an exchange rate of ₦305 to the dollar as given by

NERC. Installed capacity is the intended full-load sustained output of a facility such as a power plant, while the fixed O & M and variable O & M refers to fixed and variable operating and maintenance costs associated with the plant. The study assumed a replacement cost of 5% of the capital cost of equipment as suggested by engineers from NERC.

6.9.1 Calculation of life cycle cost of energy technologies

LCC for the selected energy technologies was calculated using suitable values for the inputs. Input such as initial capital cost, operating and maintenance cost, fuel cost and environmental cost are aggregated to arrive at the figures presented in Table 6.3 below. The study focused only on the cost of externalities associated with the environment arising from the utilisation of fossil fuel due to lack of data. Data on CO_2 emissions profile were obtained from Roche et al. (2017). Costs were calculated using the various formulae stated above.

Table 6.3: Total life cycle cost of technologies ($Kw/yr)

Energy options	Environmental costs	Replacement cost	O & M cost	Fuel cost	Capital Cost
GAS	1,980,000	12,000,000	900,360,000	198,000,000	240,000,000
PV	0	56,525.000	8,567,100.000		1,130,500
BIO	0	17,550,000	807,358,500	7,200,000	351,000,000
WIND	0	265,600	18,720,000		5,312,000
DIESEL	272.700	48,750	675,675	810,000	975,000
HYDRO	0	870,000	96,301,800	4	17,400,000
COAL	1,184,400,000	1,911,000	1,680,052,500	267,750,000	38,220,000

Source: Author’s computation

Table 6.3 presents the life cycle costs associated with energy options. A look at the table shows that gas, biomass and coal are the most expensive options. Diesel seems better on cost but has some environmental costs. Solar and wind are relatively cheaper, followed by hydro, with no environmental costs.

6.9.2 Environmental costs/benefits

It has been debated that the valuation of environmental effects on energy production plays a significant role in the competitiveness of renewable energy options and that emissions increase as the level of energy efficiency falls (van der Zwaan and Rabl, 2003). During energy production, external effects are integrated into the emissions produced during the various phases of electricity production and distribution. In particular, these depend on the characteristics of the technology under consideration as well as the quantity of fossil fuel used. According to the World Climate Change Vulnerability Index, Nigeria is among the ten most vulnerable countries when considering climate change. Estimates also show that Nigeria's GDP loss from climate change is about 2-11 per cent per annum. Although it is difficult in practice to assess and monetise all environmental impacts, one method used in literature is to determine the costs of limiting GHG emissions to safe levels (Kruyt et al., 2009).

This study employed cost-related data based on widely accepted EPA-defined GHG direct emission profiles of various production sources. The range of possible costs of carbon chosen for this study are (40, 60 and 100 USD/tCO_2e), which offers a representative sample of the possible costs to Nigeria, considering the peculiarity of the country in terms of vulnerability to climatic shocks and trends, in particular to floods and droughts.

Table 6.4: EPA-defined greenhouse gas (GHG) direct emission profiles

GHG Emissions	Emissions profile (kgCO2e/kWh)	Additional cost (cents/kWh) USD 40-60/tCO2e	USD 100/tCO2e
Gas	0.55	2.2-3.3	5.5
Coal	0.94-0.98	3.7-5.9	9.3-9.8
Diesel	0.101	4.0-6.1	10.1

Source: Roche et al. (2017)

Table 6.5: Total environmental cost/Kw/yr in US$

	Output (IC*CF*300)	CO_2 emissions	$ costs	CO_2 cost	Environmental costs
GAS	60,000,000	0.55	0.06	0.03	1,980,000
PV		0	0.06	0.00	0
BIO		0	0.06	0.00	0
WIND		0	0.06	0.00	0
DIESEL	45,000.00	0.101	0.06	0.01	272.700
HYDRO		0	0.06	0.00	0
COAL	21,000,000,000	0.94	0.06	0.06	1,184,400,000

Source: Author's computation

Table 6.5 presents the environmental costs associated with each energy options. All energy options have some impact on the environment. Although, alternative energy options such as wind and solar also have environmental impact in terms of land use, the environmental impact from energy production and use represent the largest source of greenhouse gas emissions worldwide and are mostly associated with conventional energy options as shown in Table 6.5. In this case, gas, diesel and coal have environmental costs while solar, wind, biomass and hydro have zero environmental costs.

Table 6.6: Total life cycle cost analysis of energy options (US$KW)

	LCC/yr.	NPV of LCC	Capital Cost	Total LCC
GAS	1,112,340,000.0	9,970,268,398.1	240,000,000.000	10,210,268,398.1
PV	8,623,625.0	10,133,042.4	1,130,500.000	11,263,542.4
BIO	832,108,500.0	7,458,461,514.7	351,000,000.000	7,809,461,514.7
WIND	18,985,600.0	170,174,162.3	5,312,000.000	175,486,162.3
DIESEL	1,534,697.7	13,755,999.0	975,000.000	14,730,999.0
HYDRO	97,171,804.0	962,249,900.3	17,400,000.000	979,649,900.3
COAL	3,134,113,500.0	31,035,756,039.5	38,220,000.000	31,073,976,039.5

Source: Author's computation

Table 6.6 presents the total life cycle costs of all energy options. LCC per year is the costs associated with each energy option per year, this is then discounted from year zero up to year 20 for all energy options except hydro and coal which have 40 years life span to arrive at the total life cycle cost. Capital cost is a one-time occurrence cost, hence it is excluded from the discounting process. Capital cost is added after discounting to arrive at the total life cycle cost. One of the advantages of LCC is that it allows for the comparison between projects having different costs. A glance at the table reveals that coal gas and biomass have the highest LCC while solar, diesel, wind and hydro have the lowest LCC.

6.9.3 Financial benefits

Economic benefits such as revenue from the sale of the electricity/power, employment generation, reduction in greenhouse emissions, and reliable energy supply leading to business sustainability are identified and expressed in monetary values. The monetary values of the expected costs and benefits are then adjusted with an appropriate discount factor to ensure that all inflows of benefits and outflows of project costs over a period of time (which occurs at different points in time) are expressed on a common basis in terms of their net present value (Rozylow, 2013).

Benefits such as price stability and security of energy supply are often considered at the domestic level. At the global level, the positive environmental impact is the near-zero GHG emissions of renewable technologies. However, other benefits are considered, for example employment benefits.

In this study, to arrive at the financial benefits, the revenue generated from the sales of electricity was used. Elements such as the installed capacity and the capacity factor are essential in determining the profitability of the technologies. The total energy generated was multiplied by tariffs as given by NERC to each of the energy options. This was used to determine the profitability of energy technologies.

Annual financial benefits = Quantity produced X tariffs

Where Qty = $Qty = \frac{(kwh * production)}{(1+r)^{N}}$ … (6.7)

Table 6.7: Annual financial benefits (values in KWh/yr.US $)

	Output (IC*CF*Hrs.*300)	Tariff	Financial Benefits
GAS	14,400,000,000.000	0.0787	1,133,280,000.000
PV	86,640,000.000	0.0246	2,131,344.000
BIO	525,600,000.000	0.0246	12,929,760.000
WIND	280,320,000.000	0.0246	6,895,872.000
DIESEL	13,140,000.000	0.0787	1,034,118.000
HYDRO	34,164,000,000.000	0.0426	1,455,386,400.000
COAL	30,660,000,000.000	0.0787	2,412,942,000.000

Source: Author's computation

Table 6.7 presents the expected annual financial benefits from all energy options. The tariff used is given by NERC. The tariffs used are as determined by NERC which determines and ensures that the price of electricity to be paid to producers in the Nigerian Electricity Supply Industry (NESI) is at the level required by an efficient new entrant to cover its life cycle costs (including its short-run fuel and operating costs and its long-run return on capital invested). NERC enacted three types of tariff orders according to each of the sectors in the Nigerian Electricity Supply Industry (NESI): generation, transmission and distribution (the MYTO-2 Tariff Orders). In this study, the tariff for the generation sector was used as presented in Table 6.7. Results in Table 6.7 showed that coal, hydro and gas have the highest financial benefits while diesel, wind, solar and biomass have the least benefits.

6.9.4 Employment benefits

Benefits due to new employments are important positive externalities. One of the arguments for energy is its ability to create jobs across all technologies, with a high concentration in the same technologies that account for a majority of the employment today. According to IRENA (2017), doubling the share of renewables is expected to increase direct and indirect employment in the energy sector to 24.4 million by 2030 worldwide. In Nigeria, two sectors that can create jobs in the hundreds of thousands are the generation sector and the indirect job creation sector (IRENA, 2015). According to the Nigerian Economic Summit Group working with the Job Creation Unit under the Vice Presidency Office, over 500,000 direct jobs could be created from renewable energy generation, as well as indirect jobs.

However, employment opportunities also exist for conventional energy options. Using estimates from the National Bureau of Statistics (NBS) report survey in 2014, out of the total 10.97 million people that were employed in 2013, the oil and gas sector or the fossil fuel sector accounted for 582 jobs, representing 0.01 per cent of the total. Employment is seen as a social opportunity cost that uses up labour resources that could otherwise be available for alternative social purposes (Boardman, 2006). In the case of Nigeria, this was not considered due to the high level of unemployment. Based on this information, the employment benefit was calculated. According to Rozylow (2013), to estimate the social benefit of additional employment, the number of workers employed is multiplied by the wage for which the workers would be employed. This study followed this method and calculated the employment benefits for all technologies.

Following the available information stated above, basic assumptions were made. We assumed that investment in hydropower will create a total of 100,000 jobs over its lifespan (40 years), while solar, biomass and wind will create 50,000, 20,000 and 30,000 jobs respectively, according to IRENA (2016). Investment in any of the conventional energy technologies was assumed to create a total of 200,000 jobs based on the report from NBS (2014). A diesel plant supplying electricity to a community and also powering a market is expected to provide about 20,000 jobs through its lifetime. The study assumed the current prevailing minimum wage of #18,000/month to arrive at $236,065,573 million from year zero to year 40 for hydropower. Similar calculations were done for all energy options as shown in Table 6.8 below.

Table 6.8: Estimation of benefits from energy technologies (values in $)

Items	Financial benefits	Employment benefits	Total benefits
Gas	1,133,280,000.000	412,170,491.00	13,852,379,839.98
Solar PV	2,131,344.000	212,459.00	21,008,275.33
Biomass	12,929,760.000	354,098,360.00	3,289,793,467.86
Wind	6,895,872.000	354,098,360.00	3,235,709,749.89
Diesel	1,034,118.000	35,409.00	9,586,521.43
Hydropower	1,455,386,400.000	236,065,573	17,918,536,635.16
Coal	2,412,942,000.000	412,170,491.00	27,975,854,114.64

Source: Author's computations

Table 6.8 presents the benefits associated with the energy options in consideration. The total benefit is the addition of financial and employment benefits. Financial and employment benefits are calculated based on the information stated above. The total benefits are the discounted NPVs of each energy option. The table shows that coal, hydro and gas have the largest total benefits, while diesel has the smallest total benefit. The difference in benefits could be attributed to the efficiency in capacity factor that results in a large quantity of energy being produced by each energy option.

6.9.5 Economic viability of energy options

This section is the essence of the cost-benefit analysis. There are different types or methods of analysis used in CBA to determine the economic efficiency of a project. One of these methods is the Benefit Cost Ratio. BCR is a criterion used in CBA for project investment and is defined as the total amount of discounted value of benefits divided by the total amount of discounted value of costs. For project assessment, if BCR > 1, it implies that benefits exceed cost, hence the project is economically satisfactory. If BCR = 1, it implies that benefits are equal to costs, and the project will break even. But if BCR < 1, this implies that costs exceeds benefits, and the project is not economically satisfactory. The advantage of using BCR is that it helps to determine if an investment is socially efficient and simplifies decision making. It should be noted that any project with a value above 1 has a higher risk of success while any project with a value below 1 has a higher risk of failure. Hence, success or failure may occur on either side of the ratio.

In order to cater for the weakness of BCR, we employed cost effectiveness analysis by calculating the average cost of the various energy options. LEC eliminates options that are associated with total lower costs which are relatively inefficient in output. This implies eliminating unproductive or ineffective options. Inefficient options are projects which, given the same amount of output, present a higher cost than others, while ineffective options are options that for less output produce the same or higher costs. The values of BCR and LEC are presented in Table 6.10.

Once the project impacts have been converted into their cash flows and the appropriate discount rate estimated, all benefits and costs are discounted while the levelised cost and benefit cash ratio methods are then applied to measure the project's viability. Tables 6.9 and 6.10 present the base case scenarios using the discount rate of 11 per cent and 60 USD/tCO2e.

6.9.6 Levelised cost of energy supply

To calculate the cost-effective analysis, levelised cost (LEC) is a measure chosen as decision criteria for the choices of viable energy options (Angelis-Dimakis et al., 2008). It is used in order not to eliminate options that generate lower total cost but are relatively inefficient in output. Using the EPA-defined GHG direct emission profiles data in Table 6.4 above, 40 and 100 USD/tCO2e are chosen to calculate the lower and higher bound scenarios respectively. 60 USD/tCO_2e is used as the base as presented in Table 6.9 below.

Table 6.9: Levelised cost of energy @ 60 USD/tCO_2e (base case)

Items	LCC	QTY KWh	LEC
GAS	10,210,268,398.1	14,400,000,000.000	0.709
Solar PV	11,263,542.4	86,640,000.000	0.130
Biomass	7,809,461,514.7	525,600,000.000	14.858
Wind	175,486,162.3	280,320,000.000	0.626
Diesel	14,730,999.0	13,140,000.000	1.121
Hydropower	979,649,900.3	34,164,000,000.000	0.029
Coal	31,073,976,039.5	30,660,000,000.000	1.014

Source: Author's computation

Table 6.9 presents the levelised cost of energy technologies analysis of fossil energy and renewable energy options in Nigeria. It compares per unit cost of generating energy from fossil energy options and renewable energy options over a specified period. Table 6.9 shows that LEC varies from 0.03 to 14.86 $/KWh. Accordingly, a higher LEC implies a higher cost of generating energy. Therefore, the most efficient energy options are hydropower followed by solar, wind, and gas. The most inefficient options are biomass, diesel and coal. This implies that that renewable energy options are highly competitive with fossil energy sources when cost of emissions is considered.

Table 6.10: Comparative analysis of BCR and LEC in US$/KWh (base case)

Options	LCC	Benefits	BCR	Rank	LEC	Rank
Gas	10,210,268,398.1	13,852,379,839.98	1.4	4th	0.709	4th
Solar	11,263,542.4	21,008,275.33	1.9	3rd	0.130	2nd
Biomass	7,809,461,514.7	117,163,238.19	0.02	7th	14.858	7th
Wind	175,486,162.3	3,235,709,749.89	18.4	1st	0.626	3rd
Diesel	14,730,999.0	9,586,521.43	0.7	6th	1.121	6th
Hydro	979,649,900.3	17,918,536,635.16	18.3	2nd	0.029	1st
Coal	31,073,976,039.5	27,975,854,114.64	0.9	5th	1.014	5th

Source: Author's computation

Table 6.10 compares the Benefits Cost Ratio with the LEC of each of the energy options analysed for possible infusion into the energy portfolio of Nigeria. From the table, a combination of energy technologies appears to be cost competitive in Nigeria based on the results of BCR and LEC. The based case results of the BCR show that wind, hydro, solar and gas have high returns as their BCR are higher than 1 compared to that of coal, diesel and biomass. As observed earlier, costs of generating fossil energy are higher when emissions are considered, leading to higher LEC for all fossil technologies.

However, despite the cost of CO_2 emissions in the case of gas, the LEC is relatively low when compared to coal, making gas a feasible option to be included in the portfolio mix. Looking at the ranking using LEC, hydro is most feasible followed by solar, wind and gas. BCR presents a different but similar result in terms of ranking. Wind is the most feasible, followed by hydro, solar and gas.

The next section presents the remaining cases in the sensitivity analysis.

6.9.7 Sensitivity analysis

This section presents the methods used to assess the sensitivity of the changes in the variables used in CBA. This study carried out this analysis by varying some of the variables to determine the effect of change on the discounted LCC and Benefits values. According to Sartori et al. (2015), a guiding criterion is to consider those variables for which a variation of $\pm 1\%$ of the value adopted in the base case give rise to the variation of more than 1% in the values of NPV. Thus, a low discount rate of 8 per cent in which more weight is placed on the impacts occurring further in the future is suggested for the optimistic scenario, while a higher discount rate of 15 per cent is suggested for the pessimistic scenarios.

In addition, lower and higher bound scenarios of 40 and 100 USD/tCO2e, respectively were used to account for changes in the cost of emission. Finally, lower and higher tariffs were applied to see the effect of changes on benefits. Tables 6.11-6.12 present the optimistic scenario vis-à-vis the pessimistic scenarios for the sensitivity analysis.

Table 6.11: Analysis of energy supply (optimistic) @ 40 USD/tCO_2e and WACC 8%

Items	QEO (KWh)	Benefit	LCC	BRC	LEC
Gas	1,440,000,000.000	73,133,934,246.296	56,294,153,308.60	1.30	3.909
Solar PV	6,840,000.000	89,348,357.914	435,958,865.92	0.20	5.032
Biomass	43,200,000.000	484,183,027.348	42,308,341,526.69	0.01	80.495
Wind	23,040,000.000	18,109,095,749.104	962,621,417.33	18.81	3.434
Diesel	1,080,000.000	49,555,798.462	78,354,358.12	0.63	5.963
Hydro	1,404,000,000.000	430,926,673,712.550	26,396,023,795.76	16.33	0.773
Coal	1,260,000,000.000	711,983,352,536.813	743,662,577,073.17	0.96	24.255

Source: Author’s computation

Table 6.12: Analysis of energy supply (pessimistic) @ 100 USD/tCO_2e and WACC 15%

Items	QEO (KWh)	BENEFIT	LCC	BCR	LEC
Gas	1,440,000,000.000	63,546,601,505.461	132,554,078,253.22	0.48	9.2
Solar PV	6,840,000.000	50,516,043.257	1,025,704,421.19	0.05	11.8
Biomass	43,200,000.000	1,958,917,377.933	1,958,917,377.933	0.02	188.7
Wind	23,040,000.000	42,155,601,326.494	2,260,993,414.51	18.6	8.07
Diesel	1,080,000.000	15,139,379.543	183,334,217.60	0.08	13.9
Hydro	1,404,000,000.000	866,220,024,876.289	198,923,598,743.22	4.35	5.8
Coal	1,260,000,000.000	1,063,438,565,434.260	8,031,698,692,645.49	0.13	261.9

Source: Author’s computations

Tables 6.11 to 6.12 present the scenario analysis of optimistic and pessimistic energy supply by the various options. The output produced does not change because tariffs and cost of CO_2 emissions only reflect on the benefits and total cost of production. A change in tariffs and cost of CO_2 emissions appears to have similar effect on benefits and total cost, so that a reduction in tariffs leads to a reduction in total benefit and a reduction in CO_2 has the same effect on total cost and vice versa. However, a reduction in the discount rate increases both benefits and cost at the same time, while an increase in discount rate reduces benefits and cost. The combined effect of the scenarios are shown in BCR and LEC values as presented in Tables 6.13 and 6.14 below.

Table 6.13: Comparative scenario analysis of levelised costs

Projects	LEC Optimistic	LEC Base	LEC Pessimistic	Average	Rank
Gas	3.909	0.709	9.2	4.61	3rd
Solar PV	5.032	0.130	11.8	5.65	4th
Biomass	80.495	14.858	188.7	94.68	7th
Wind	3.434	0.626	8.07	4.04	2nd
Diesel	5.963	1.121	13.9	6.99	5th
Hydro	0.773	0.029	5.8	2.20	1st
Coal	24.255	1.014	261.9	95.72	6th

Source: Author's computations

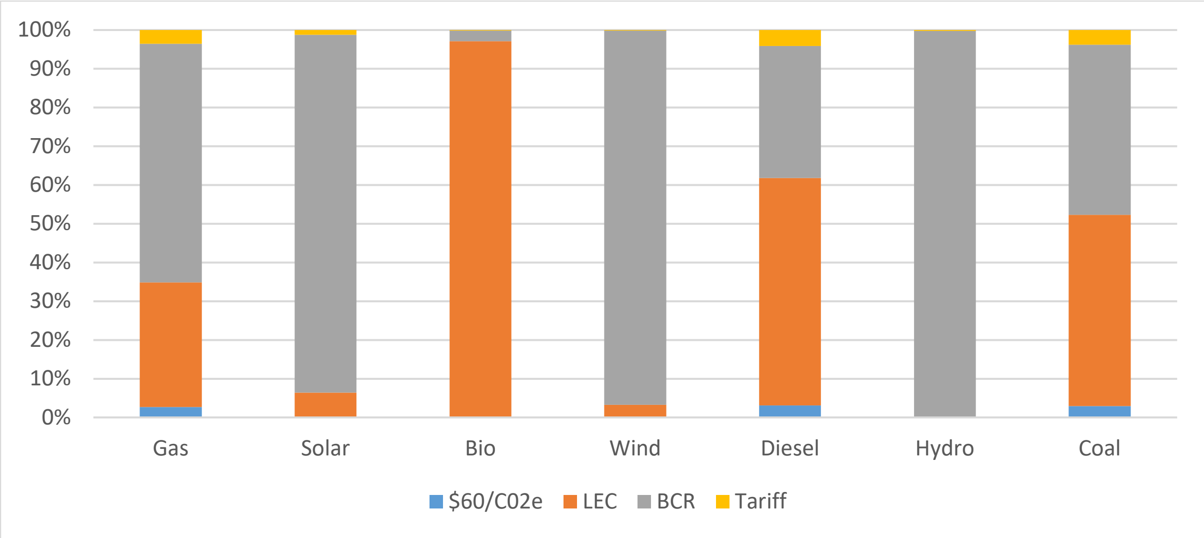
Table 6.14: Comparative scenario analysis of benefit costs ratio

Projects	BCR Optimistic	BRC Base	BCR Pessimistic	Averages	Rank
Gas	1.30	1.4	0.48	1.06	3rd
Solar PV	0.20	1.9	0.05	0.72	4th
Biomass	0.01	0.02	0.02	0.02	6th
Wind	18.81	18.4	18.6	18.60	1st
Diesel	0.63	0.7	0.08	0.47	7th
Hydro	16.33	18.3	4.35	12.99	2nd
Coal	0.96	0.9	0.13	0.66	5th

Source: Author's computations

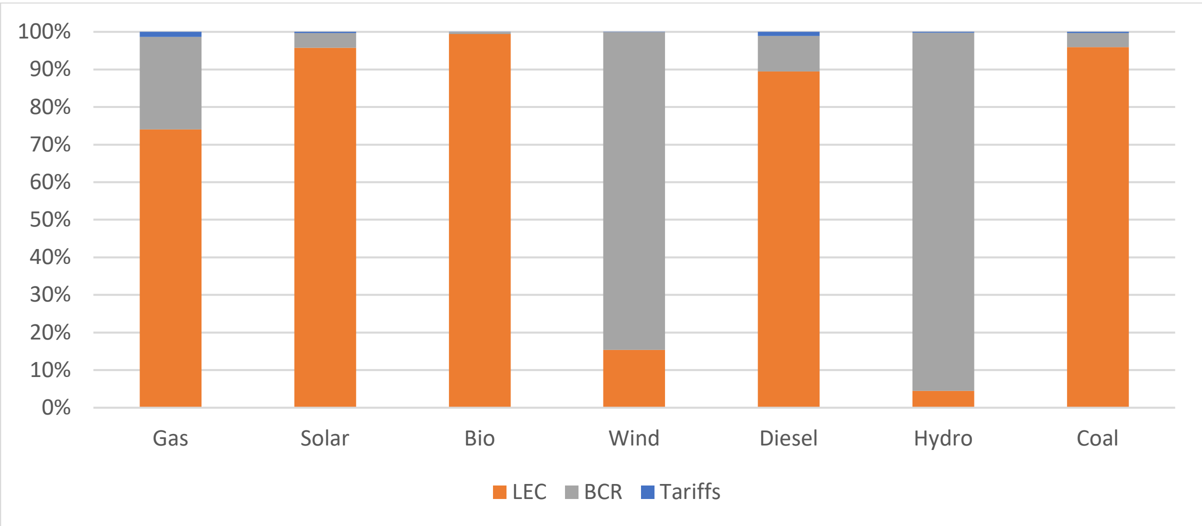
Tables 6.13 and 6.14 present the LEC and BCR result calculations for energy scenarios and Figures 6.1 to 6.3 below show the lower and upper bounds scenarios of 40, 60 and 100 USD/tCO_2e and tariffs for the base, optimistic and pessimistic cases. From the perspective of costs and benefits of energy supply, hydro, wind, gas and solar are more economically viable than the other options. Results also show that the inclusion of environmental costs makes renewable options fully competitive with fossil fuel generation. At a relatively low cost of carbon (40 USD t/CO_2e), and at an increased cost of carbon to 60 and 100 USD/tCO_2e, renewable technologies become more competitive with conventional fossil power generation. In all cases, hydro, wind and solar PV energy resources remain the most competitive renewable energy resource.

Figure 6.1: Comparative analysis of LEC, BCR and tariffs in KW @ \$60/tCO_2e



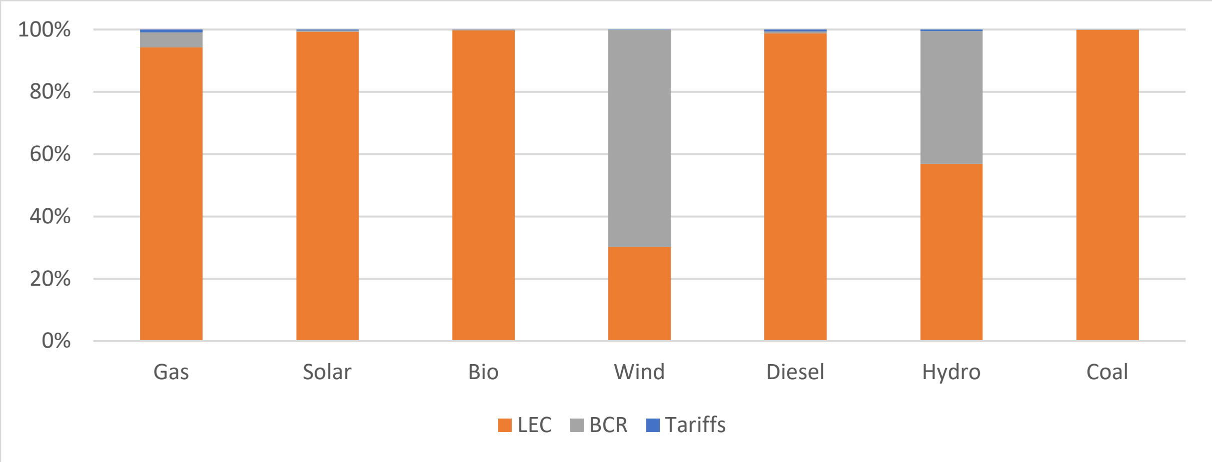
Source: Author's computations

Figure 6.2: Comparative analysis of LEC, BCR and tariffs in KWh @ \$40/tCO_2e



Source: Author's computations

Figure 6.3: Comparative analysis of LEC, BCR and tariffs in KW @ $100/tCO_2e$



Source: Author's computations using EIA data

Figures 6.1 to 6.3 above show that the reduction in tariffs coupled with a reduction in discount will translate into a reduction in benefits. The reduction in CO_2 has little effect on the overall cost of energy production as other variables such as initial capital cost, O & M costs etc. do not change as a result of changes in tariffs and CO_2 emissions. The upper bound of 100 USD/tCO_2e and increased tariffs led to a further increase in the cost of production as can be seen from the values of LEC. The cost of CO_2 emissions for all fossil energy technologies remain on the high side, making renewable energy more competitive. Results further show that coal and diesel have the highest cost of production: this could be attributed to the high emissions associated with coal and diesel energy technologies.

The results compare with those of other studies and countries. In the case of India, Kolhe et al. (2002) analysed the economic viability of a stand-alone solar photovoltaic PV system with the most likely conventional alternative system, i.e. a diesel-powered system, for energy demand through sensitivity analysis using a life-cycle cost computation. The analysis shows that PV-powered systems are the lowest cost option at a daily energy demand of up to 15 kW/h, even under unfavourable economic conditions. When the economic parameters are more favourable, PV-powered systems are competitive up to 68 kWh per day. Dimakis et al. (2008) employed a cost effectiveness method for renewable energy success in the island of Lemnos, Greece, and concluded that the excess of both electricity and thermal energy demand can be met in the near future without any significant changes in existing infrastructure, while other options should be considered for a more extended time horizon.

Thiam (2010) employed life cycle analysis in Senegal and found a similar result that renewable energy is competitive with fossil energy supply when considering rural communities. Barimani (2016) employed cost-benefit analysis to renewable electricity in Iran and explained that when external costs in economic transactions and social cost price of fossil fuel electricity are considered along with the operation of full subsidy targeting law enforcement conditions, private sector investors' opportunity in the industry would improve, and this will subsequently increase the share of renewable electricity relative to fossil fuel electricity in the Iranian energy basket. An important lesson from these analyses is that renewable energy resources in recent times have become very competitive when environmental costs are considered. With adequate policies, the deployment of new clean technology should alleviate the environmental concerns of GHG emissions and reduce the energy deficit currently faced in the country.

Therefore, the study has shown that it is important at this stage to note from a supply point of view that hydro and gas remain substantial energy sources for Nigeria. The analysis so far shows that from a cost and benefit point of view, hydro, wind and solar sources are the most competitive and viable options amongst the available energy sources. This has implications for rethinking strategies for energy portfolio options in Nigeria. An obvious portfolio from the analysis would have to include hydro, wind, solar and gas. This is shown in Table 6.17 following a similar analysis carried out by the Energy Commission of Nigeria (ECN).

Table 6.15: Primary energy consumption in Nigeria (2010)

Energy type	**Consumption in TOE**	**% of Total**
Hydropower	641,947.38	0.60
Biofuels	72,872.800	68.52
Petroleum	8,874.342	8.34
Coal	5.600	0.01
Gas	23,955,518.08	22.53
Total	**106,345,168. 03**	**100**

Source: ECN (2013)

In Table 6.15, the total primary energy consumption basket is presented. From the table, it can be seen that energy consumption from biofuels is 68.5 per cent which is more than half of the primary energy consumption. Oil and gas account for 8.3 per cent and 22.5 per cent respectively. Despite efforts to narrow the huge gap between energy demand and supply, statistics have shown that not much progress has been made as shown in the table below.

Table 6.16: Nigerian total primary energy consumption in % (2013)

Energy Type	Energy Consumption (%)
Oil	13
Gas	12
Biofuels	74
Hydro	1
Wind	0
Solar	0

Source: EIA (2016)

Table 6.16 presents the Nigerian total primary energy consumption. According to the EIA estimates, total primary energy consumption in Nigeria was about 4.8 quadrillion British thermal units. Traditional biomass and waste (typically consisting of wood, charcoal, manure and crop residues) accounted for 74%. The high share of biomass is off-grid which is mainly used for heating and cooking in rural areas. The table shows that oil, gas and hydro constitute less than 50 per cent of the total primary energy consumption. This is of major concern considering the international commitment made by the government.

Nigeria has committed to international agreements such as the Paris Climate Agreement and has promised to improve energy efficiency by 2 per cent annually, leading to a 30 per cent reduction by 2030 (UNFCCC, 2016). However, current energy consumption per capita is one of the lowest compared to other developing countries as shown earlier in this study. Therefore, this study proposes an energy consumption basket based on the quantity of energy produced by each energy option and the costs and benefits associated with each energy options that should be included in the energy portfolio of Nigeria.

Table 6.17: Proposed energy consumption basket in Nigeria (2018)

Energy Option	QEO (MWH)	% of Total
Hydro	1,404,000,000.00	33.60
Solar PV	6,840,000.00	0.16
Wind	23,040,000.00	0.55
Gas	1,440,000,000.00	34.46
Coal	1,260,000,000.00	30.15
Biomass	43,200,000.00	1.03
Diesel	1,080,000.00	0.02
Total	**4,178,160.000**	**100**

Source: Author's computations

Following the analysis in Table 6.16, Table 6.17 presents the quantity of energy produced by each energy option vis-à-vis the percentages of the total. Based on this calculation, hydropower, gas and coal have the highest percentages, while solar and wind have smaller percentages. These may not necessarily be the most feasible and viable energy options when total costs (environmental costs) are considered. Thus, Table 6.18 presents the proposed energy options that should be considered for the energy portfolio mix based on the benefits costs ratio (BCR) calculated.

Table 6.18: Proposed energy portfolio mix in Nigeria (2018)

Energy Option	BCR	% of Total
Wind	18.4	44.21
Hydro	18.3	43.97
Solar	1.9	4.57
Gas	1.4	3.36
Coal	0.9	2.16
Diesel	0.7	1.68
Biomass	0.02	0.05
Total	**41.62**	**100**

Source: Author's computations

Table 6.18 presents the proposed energy portfolio mix in Nigeria. Using the values for the BCR rankings, we calculated the percentages of the total in order to allocate weight to each energy options. As earlier noted, the cost and benefit analysis has shown that based on total costs and benefits associated with each energy option, wind, hydro and solar power are the preferred energy options for an optimal portfolio due to their large potential and the ease of energy supply in Nigeria.

In addition, gas is also included due mainly to its capacity efficiency. However, although Nigeria is one of the global top-10 natural gas producers, over the years gas production has been constrained by lack of infrastructure to monetise natural gas that is currently being flared, pipeline sabotage and supply disruptions which are common in Nigeria's natural gas industry. Therefore, renewable energy resources are considered economically more viable in this study, and are proposed to be included in the energy portfolio mix for an optimal energy supply, based mainly on their advantages over fossil energy resources when environmental costs and security challenges in the Niger Delta region are considered.

6.10 Conclusion and policy implications

This study presented an assessment of the economic viability of energy technologies in Nigeria for an optimal energy supply. To effectively account for all externalities, several methods – CBA, CEA, LCA, LEC, BCR and sensitivity analysis – were used to uncover the different perspectives for evaluating the costs and benefits of power generation in Nigeria. The assessment included seven different technologies: gas, solar, wind, large hydropower, biomass, diesel-powered and coal. The cost analysis showed that viable energy options with massive benefits for the Nigerian economy abound.

In Nigeria, onshore wind, biomass, and hydropower are currently competitive with coal and gas-fired power stations, despite higher investment risks for both renewables and conventional power. When costs of emissions are included, renewable energies are fully competitive with conventional generation. In off-grid generation, off-grid solar PV systems are already cost-competitive in Nigeria on a lifetime basis, but are hindered by the lower upfront costs of diesel and petrol generators.

Over the years, Nigeria has faced challenging energy situations due to shortages of energy supply to energy demand with adverse impact on economic growth. In such situations, a large amount of consistent energy supply is required to fuel growth and sustainable development. The current energy portfolio of the country is only able to meet the energy needs of about half of the country's population, while the other half lack access to a reliable and constant energy supply. Thus, the study has shown that it is important at this stage to note the most competitive and viable options amongst the available energy sources. This has implications for rethinking strategies for energy portfolio options. Therefore, based on this study, an obvious portfolio from the analysis would have to include hydro, wind, solar and gas for an optimal energy portfolio in Nigeria.

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CHAPTER SEVEN
CONCLUSIONS AND POLICY RECOMMENDATIONS

7.1 Summary of findings and conclusion

This thesis is a collection of three essays which have examined the link between energy consumption, the environment and economic growth in Nigeria. Specifically, the research examined the effects of renewable and non-renewable energy sources on economic growth and also determined the energy options that are economically viable for an optimal energy mix in Nigeria. Finally, the environmental impact of economic growth was examined within the context of the environmental Kuznets curve hypothesis.

To achieve the first objective of this study, the essay evaluated the effects of energy options (renewable and non-renewable energy consumption) on economic growth in Nigeria, using the ARDL bounds testing approach to cointegration by Pesaran et al. (2001). The paper evaluated the effects of energy consumption (renewable and non-renewable energy on economic growth in Nigeria. Two models were specified to determine the different growth effects of a disaggregated (renewable and non-renewable) and aggregated energy consumption energy on growth.

In the disaggregated model, the analysis showed that there seems to be a statistically significant negative effect of renewable energy on economic growth in the long run. Although the case for renewable energy is centred on the premise that renewable energy helps to increase access to clean energy, for a developing country such as Nigeria with large fossil energy resources, renewable energy utilisation is still very low due to the limited development of renewable energy resources in the country.

The results also showed that GDP responds positively to fossil fuel energy consumption in the short and long run. Thus, an increase in fossil fuel energy use will increase economic growth significantly with a long-run elasticity coefficient of 0.056. Similarly, in the aggregated model, the results appeared to be statistically significant, implying that energy consumption drives growth in Nigeria. Hence, a unit increase in aggregate energy consumption will increase growth by 1.34 units in the long run. The error correction models (disaggregated and aggregated) indicate the speed or rate of adjustment from the short-run disequilibrium to long-run equilibrium relationship between energy consumption and economic growth in Nigeria. The coefficient of ECT in both models are negative and significant.

To achieve the second objective, the paper evaluated the relationship between economic growth and CO_2 emissions in Nigeria. The study employed annual time series data from 1980-2016, using an ARDL bound testing approach to examine the long-run relationship among energy consumption, economic growth and CO_2 emissions in Nigeria. This result confirms the EKC hypothesis for Nigeria. Specifically, as economic growth increases it worsens the quality of the environment up to a level where improvements in environmental quality begin to occur with further growth. Overall results show that the net effect on the environment may be negative as the environmental degradation effect of growth is larger than the environmental quality enhancement effect.

A unique feature of this paper is the computation of the threshold effect. The linear and non-linear terms for GDP and square are 143.90 and -21.99 respectively, and both are highly significant. The calculated threshold GDP per capita of $1,862 implies that at the early stages of development, economic growth leads to an increase in carbon emission up to a threshold of $1,862 GDP per capita, after which the effect of GDP per capita on CO_2 switches to negative and economic growth leads to a decline in CO_2 emissions at the later stage of development.

The third objective of the study was to investigate the economic viability of energy options in Nigeria for financing an optimal energy portfolio. Several methods were employed – cost benefit analysis, cost effectiveness analysis, life cycle cost analysis, levelised cost analysis, sensitivity analysis and benefit cost ratio – for the assessment of seven different technologies (gas, solar, wind, large hydropower, biomass, diesel-powered and coal). Based on these methods, life cycle cost and levelised cost were used as the criteria for choosing the most economically feasible energy options to be included in the energy portfolio, and this was followed by sensitivity analysis. The results clearly revealed that when the environmental effects are taken into consideration from a cost and benefit point of view, hydro, wind, solar and gas sources are the most competitive and viable options amongst the available energy sources.

7.2 Contribution

The study makes a unique contribution to the literature in a number of ways. First, it is one of the first few studies to investigate separately the effects of energy consumption (renewable and non-renewable) on economic growth. This approach presents clarity in the literature on the different growth effects of disaggregated energy sources and its usefulness for developing countries transiting the energy growth path. The study showed that for a developing country such as Nigeria with large development gaps and slow growth in the midst of abundant renewable and non-renewable energy resources, the path to increased growth and rapid development cannot be by renewable energy alone, rather a more careful approach of combined energy sources (renewable and non-renewable) is necessary to achieve growth.

It is recognised in both the theoretical and empirical literature that energy is essential for economic growth and the relationship between them is situated in the four main hypotheses (growth hypothesis, conservation hypothesis, neutral hypothesis and feedback hypothesis). However, these hypotheses are built on aggregate energy consumption, which is largely dominated by conventional energy sources. Cheap conventional energy consumption is beneficial for economic growth, but has been identified as the major cause of anthropogenic climate change. Contrary to existing literature which is built around aggregate energy consumption, conventional and alternative energy sources could have different relationships with economic growth. This understanding is important to policy makers in focusing on a comprehensive examination of an optimal energy portfolio to drive sustainable economic growth and development while also ensuring environmental sustainability.

Secondly, this study also adds to the literature by computing the threshold effect of the Environmental Kuznets Curve hypothesis for Nigeria. The theoretical underpinning of the EKC is based on the premise that increasing income in developing countries would lead to more consumption of goods and services, whose value chains are environmentally intensive. During the early stages of economic growth, countries invest in growth-inducing activities such as infrastructure investment and energy consumption which will increase environmental footprints. During this stage, economic growth is the major development goal. This pattern will continue until a certain level of economic growth/development is achieved (threshold point) after which higher income levels will be associated with declining environmental pollution or better environmental quality. At this point, the country would have achieved higher economic growth and resources to invest in environmentally friendly economic model. China's economic development follows this pattern. Also, at this point, people's basic needs have been met and they begin to demand a cleaner environment.

Although the literature discusses at length the possibility and validity of this hypothesis and its extensions, very few studies exist on the exact threshold where the effect of growth on the environment changes, particularly in Nigeria. By incorporating nonlinear terms, this study computes the turning point (threshold) of the relationship between economic activity and the quality of environment and confirms the shape of the relationship to support the EKC hypothesis for Nigeria. A unique feature of this paper is the computation of the threshold effect. The linear and non-linear terms for GDP and square are 143.90 and -21.99 respectively, and both are highly significant.

The calculated threshold point of GDP per capita of $1,862 implies that at the early stages of development, economic growth, leads to an increase in carbon emission up to a threshold of GDP per capita of $1,862 after which the effect of GDP per capita on CO_2 switches to negative and economic growth leads to a decline in CO_2 emissions at the later stage of development. In addition, it shows that the net effect on the environment may be negative as the environmental degradation effect of growth is larger than the environmental quality enhancement effect. This helps in rethinking policy strategies that will enhance growth and improve environmental quality at the same time.

Finally, the study also makes a unique contribution of providing a pathway to identifying optimal energy portfolio in the literature. Although energy use comes from diverse sources and countries use combinations of different sources to provide energy, there is no clear pathway in the literature to come up with optimal energy portfolio choices. Given the different costs and benefits of multiple energy choices and the context of different energy endowments across countries, it is important to have a theoretically sound way of creating or proposing an optimal energy mix that is supportive of economic growth.

Generally, using conventional energy sources to drive economic growth is relatively less costly than alternative energy sources. However, given the high environmental costs of conventional energy, creating a space for alternative energy sources becomes imperative. The cost disparities between the two types of energy source make it important to determine an optimal mix in a way that sustains economic growth. Using a discounted cost benefit analysis, life cycle cost, levelised cost analysis and supply potential of multiple energy sources, this paper identifies viable energy options for Nigeria and proposes a portfolio of options which the country can consider in her energy production and use.

7.3 Conclusions

The combined evidence from the study relates to the utilisation of various energy resource options in a more sustainable manner to achieve economic growth and development in Nigeria. This is to ensure that technology and inputs for the processing and development of industrial and infrastructure projects not only meet the current economic needs but also guarantee that the natural environment which they occupy is not jeopardised. With the current situation of the economy that is highly dependent on fossil fuel, and has a persistent increased energy demand for industrial activities and chronic unemployment, especially among the youth, policies focused on a comprehensive examination of an optimal energy portfolio to drive economic growth should be implemented.

To conclude, the study has addressed key issues in the Nigerian energy sector. From the literature on renewable energy it is noticeable that renewable energy deployment is not carefully planned. There is a need to craft out renewable energy policies from a structural transformation point of view. Such policies require a regional cooperation approach to extending modern energy to rural areas at affordable prices to spur economic transformation. It is however vital that certain constraints such as capacity constraints, finance and tariff viability, political and domestic issues, security and regulation issues are dealt with. At the same time, it is important to choose the most cost-effective renewable energy source which also delivers and improves universal access to all. In this regard the study has shown that a combination of cost benefit analysis and cost effectiveness analysis to evaluate the massive investment costs and benefits of renewable energy is a step in the right direction to provide insightful policy recommendations.

7.4 Recommendations

This thesis puts forward some policy suggestions to enhance energy access, economic growth and environmental protection and to determine the optimal energy options suitable for sustainable growth in Nigeria.

Currently, the Nigerian government is fully committed to climate change and global warming programmes. However, caution must be taken to ensure that policies implemented to reduce CO_2 emissions do not affect growth negatively.

The study confirms the EKC hypothesis for the CO_2 emissions. It implies that as GDP moves beyond the EKC turning points, it is assumed that the transition to improving environmental quality takes place. Nigeria is fully committed to the Kyoto protocol programmes for sustainable growth. Therefore, options for economic growth with smaller increases in energy use should include rapid growth in service industries, massive investment in cleaner technologies, installing domestic pollution control devices, and increasing energy efficiency. The implementation of the first two involves reducing demand for energy domestically, but there will be a compensating increase in demand for energy internationally. The third option can increase demand for energy while reducing specific pollutants, as many pollution control devices use more energy. The final option, energy efficiency, reduces demand for energy and at the same time reduces energy-based pollution.

The findings from the cost-benefit analysis and cost effectiveness analysis show an orientation towards renewable technologies, as evidence points towards a higher net benefit of renewable technologies. It is important at this stage to note that from a supply point of view gas remains a substantial energy source for Nigeria. However the analysis so far shows that from a cost and benefit point of view, hydro, wind and solar sources are the most competitive and viable options amongst the available energy sources. This has important implications for energy policy making and efforts to enhance energy access in Nigeria.

The current energy portfolio of the country is only able to meet the energy needs of about half of the country's population, while half of the population lack access to a reliable and constant energy supply. The energy portfolio analysis has implications for increasing energy access. It has shown that it is important at this stage to note the most competitive and viable options amongst the available energy sources. This has implications for rethinking strategies for energy portfolio options and rapidly enhancing access. Unlike the current strategy, where the expansion of energy access has mainly focused on grid-connected fossil fuel energy sources, the analysis has shown that renewable energy sources can provide a viable option or complement for improving energy access in Nigeria. On the basis of this study, the government should build up an energy portfolio in the prioritised order of hydro, wind, solar and gas.

7.5 Limitations of the study

The study examined energy issues in Nigeria. The first paper investigated the impact of energy consumption (aggregated and disaggregated) on economic growth in Nigeria. Although the paper built on existing studies in the literature by disaggregating energy consumption into conventional and renewable energy, there is a possibility that different types of conventional energy and renewable energy sources could have different effects on economic growth due to the differences in their cost structure. Hence, further studies need to be conducted in this area. As data on the different sources of conventional and renewable energy consumption become available, more studies should be conducted in this area. The last paper analysed the various energy options for an optimal energy portfolio mix for improved energy supply in Nigeria using cost benefit analysis and cost effectiveness analysis. However, given that investments in energy sources are associated with uncertainty and high risk which could be time varying, further studies could attempt to use other methods that can capture dynamism in the cost benefit analysis and account for the time varying risk factor.

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Appendix A

Figure A.1: Model selection (energy-growth nexus): disaggregated model

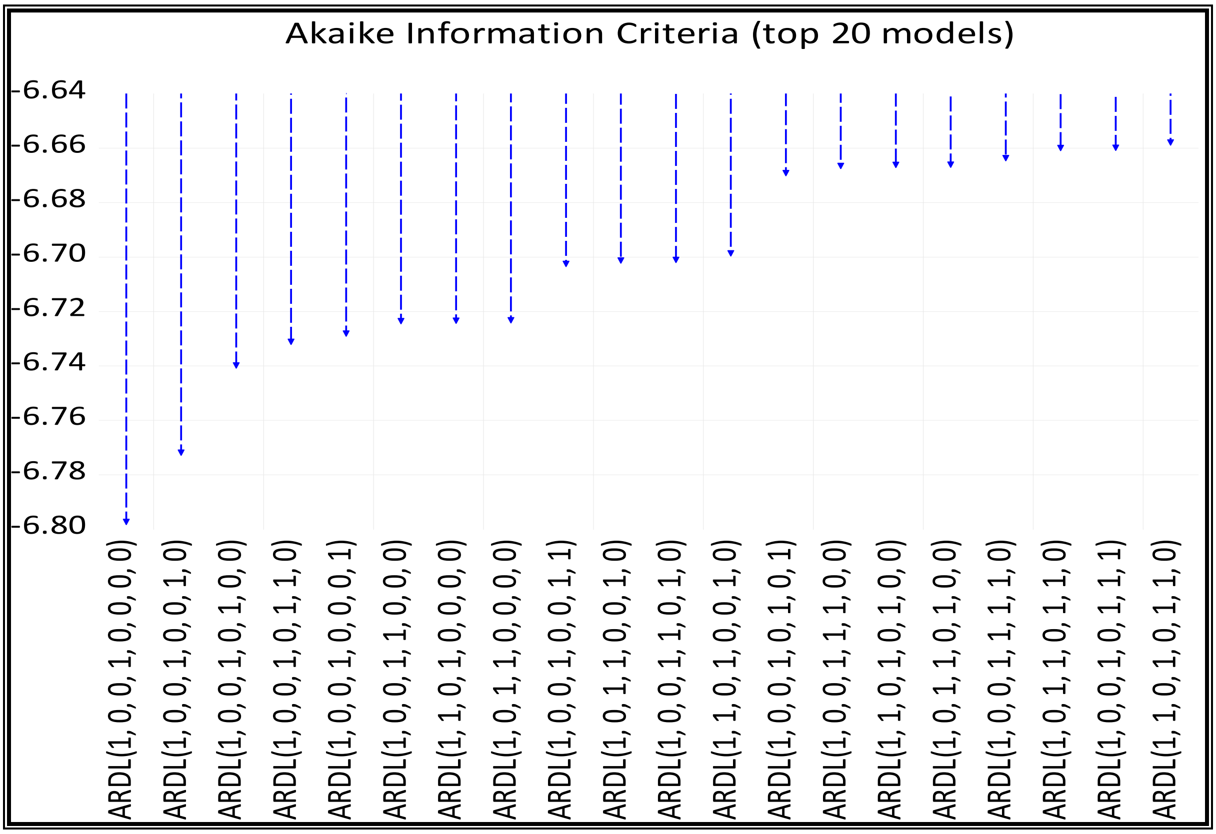

Figure A.2: Plot of actual and fitted residuals model for real output

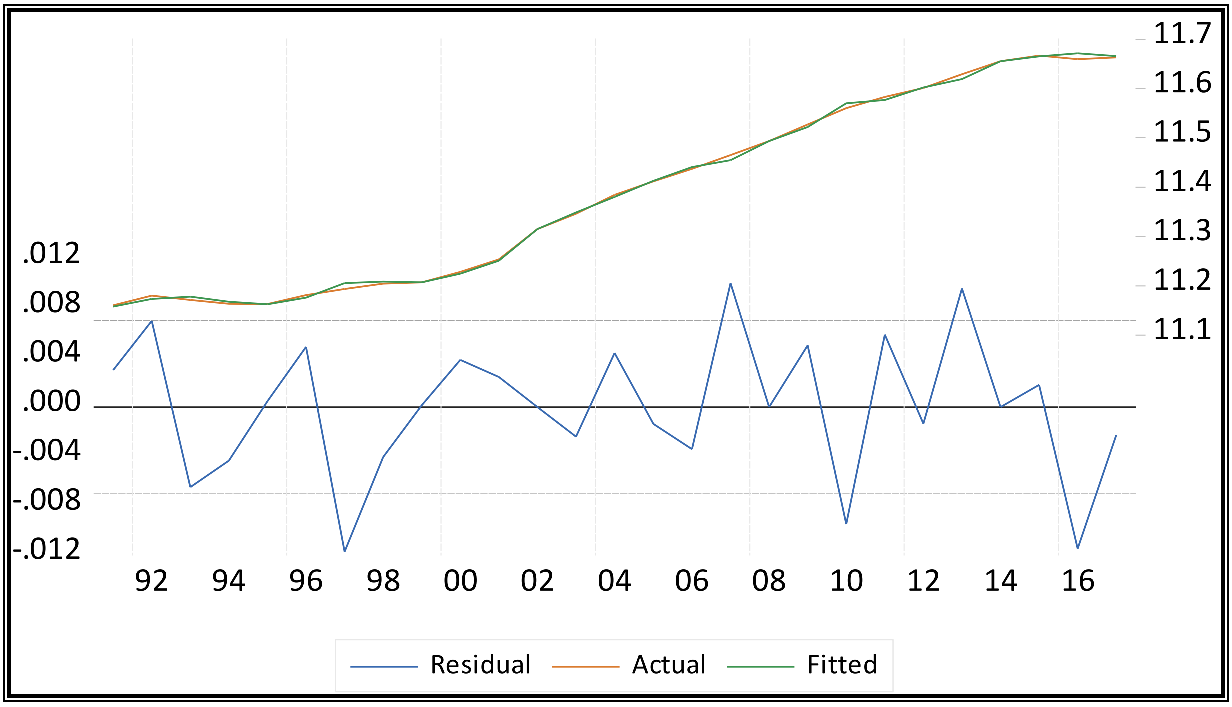

Figure A.3: Stability test: CUSUM disaggregated model

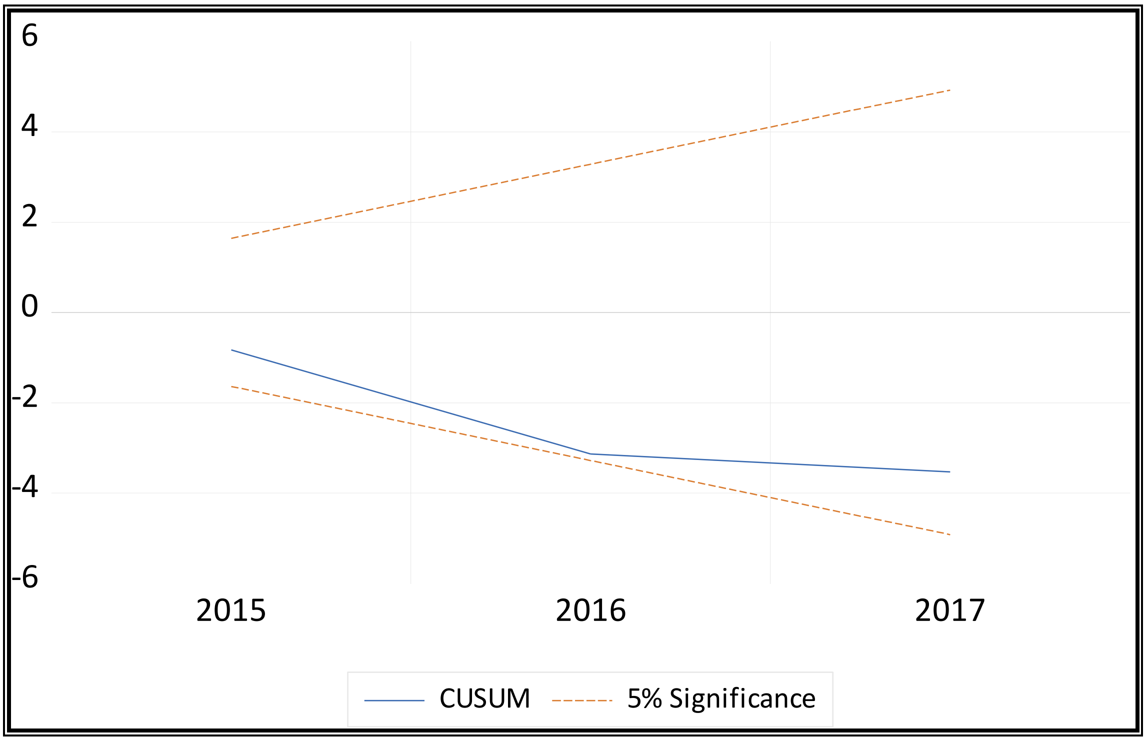

Figure A.4: CUSUMsQ disaggregated model

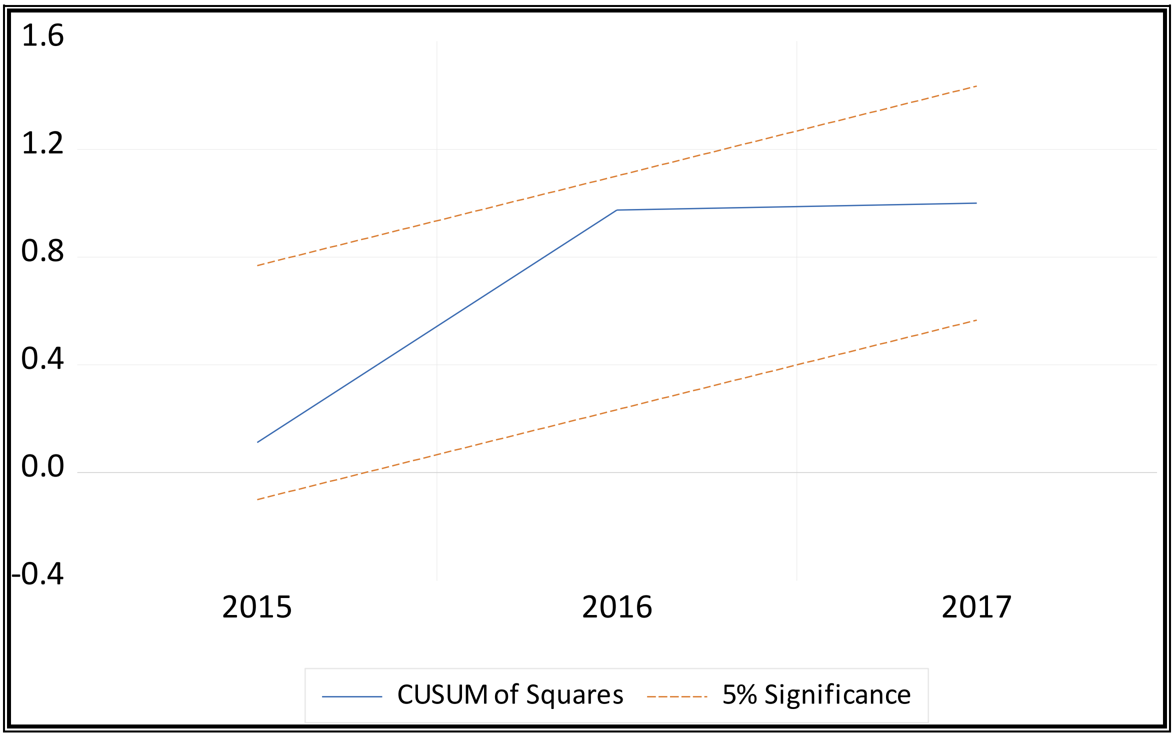

Figure A.5: Model selection (energy-growth nexus) aggregated model

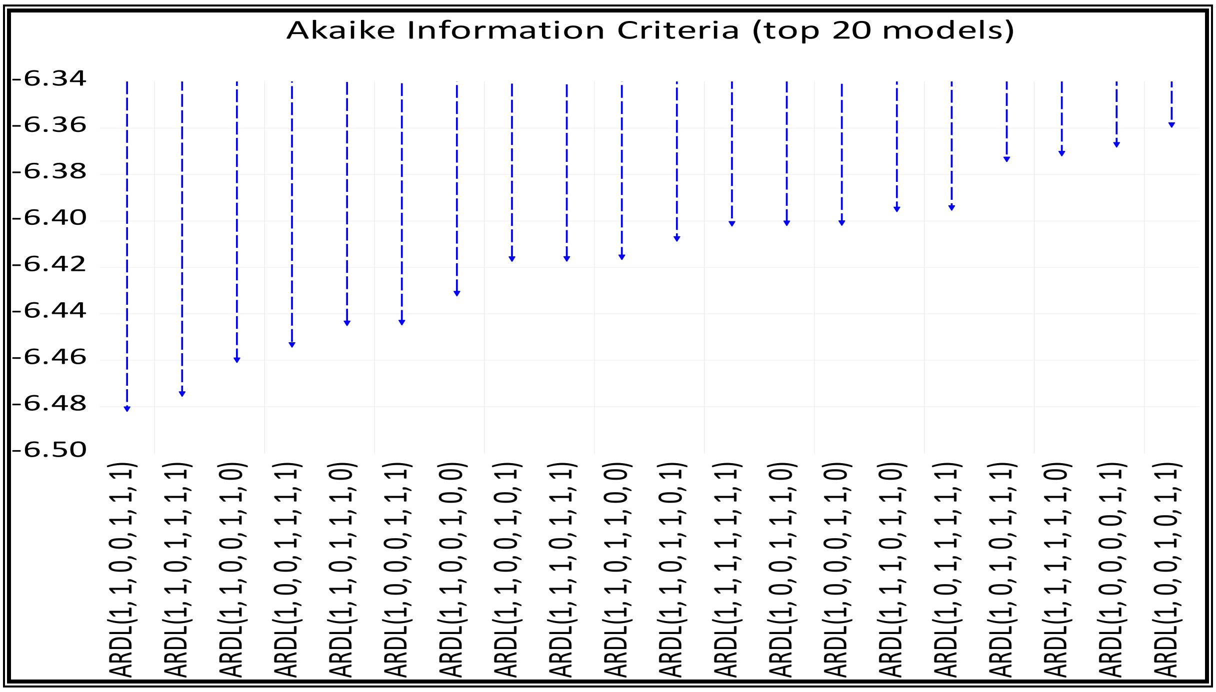

Figure A.6: Plot of actual and fitted residuals model for real output

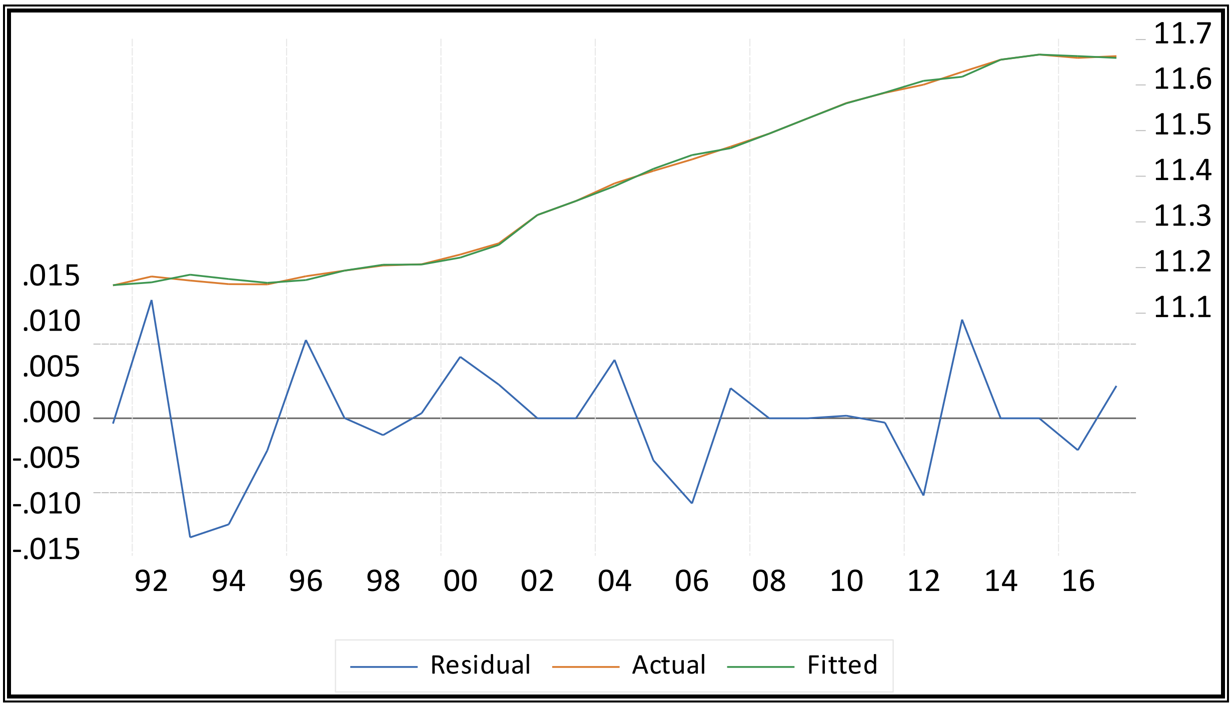

Figure A.7: Model selection EKC model

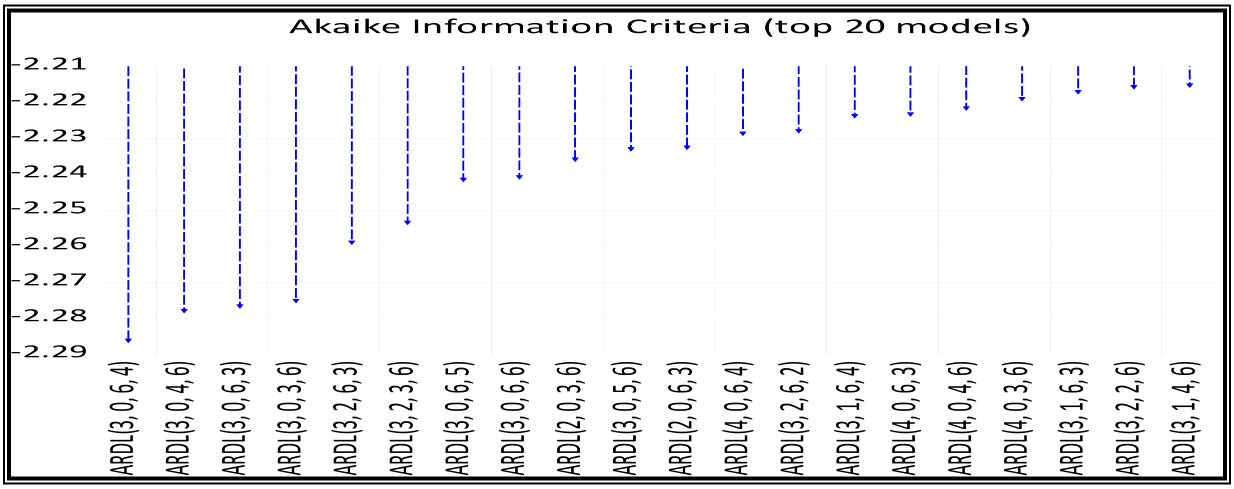

Figure A.8: Plot of actual and fitted residuals model for real output

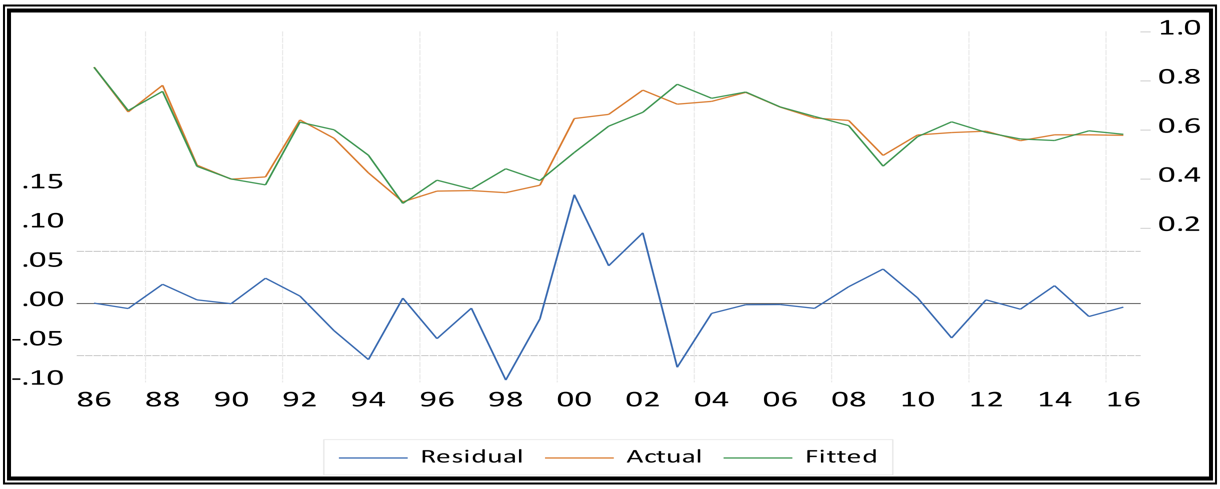

Figure A.9: Stability test: CUSUM