RETRACTED ARTICLE: Scenario analysis for low carbon development in Nigeria

Nnaemeka Vincent Emodi, Birku Reta Entele, Marc Nwosu Ogbuagu, Chineny Ogbuagu, Comfort Emodi, Adaese Saratu Augusta Emodi and Felix Chimezirim Okoro

Cogent Engineering (2016), 3: 1218818
RETRACTED ARTICLE: Scenario analysis for low carbon development in Nigeria

Nnaemeka Vincent Emodi1*, Birku Reta Entele2, Marc Nwosu Ogbruagu3, Chinenye Comfort Emodi4, Adaede Saratu Augusta Emodi5 and Felix Chimezirim Okoro6

Abstract: This study explores a scenario-based analysis of future energy consumption and GHG emissions for Nigeria between 2010 and 2040 using the LEAP model. The impact of different energy policies are analysed for the Nigerian energy system by considering four scenarios: The reference (REF) scenario, the low-carbon moderate (LCM) scenario, the low-carbon advanced (LCA) scenario, and the green optimistic (GO) scenario. By considering aggressive energy policies and strategies from LCM to LCA, and even more aggressive options in the GO scenario, we find that under the REF scenario energy demand is expected to reach 3,075 PJ and a corresponding increase in GHG emissions of 201.2 Mt Co2e by 2040. More aggressive policy intervention by the Nigerian government, as in the GO scenario, would lead to a decrease in energy demand (2,249 PJ) and GHG emissions (124.4 Mt Co2e) in 2040. A cost-benefit analysis is also carried out in the study.

Subjects: Development Studies, Environment, Social Work, Urban Studies; Economics, Finance, Business & Industry; Engineering & Technology; Environmental Studies & Management

Keywords: scenario analysis; low-carbon development; Nigeria; LEAP model; energy forecasting; low-carbon technology

ABOUT THE AUTHORS

Nnaemeka Vincent Emodi is an Energy Analyst and currently a Doctorate degree (PhD) student in Economics at the College of Business, Law, and Governance, James Cook University, P.O. Box 6811, Cairns 4870, Queensland, Australia. E-mail: nnaemeka.emodi@my.jcu.edu.au

*Corresponding author: Nnaemeka Vincent Emodi, College of Business, Law and Governance, James Cook University, P.O. Box 6811, Cairns 4870, Queensland, Australia

Reviewing editor: Sarah Bell, University College London, UK

Additional information is available at the end of the article

PUBLIC INTEREST STATEMENT

Achieving a low-carbon development involves the development of an economy based on a low carbon power sources with minimal greenhouse gas emission. In this study, we applied a scenario analysis using a bottom-up approach to model a set of low carbon pathways for the Nigerian energy sector from 2010 to 2040. The LEAP model was used to develop four scenarios: The reference (REF), low-carbon moderate (LCM), the low-carbon advanced (LCA), and green optimistic (GO) scenarios. Various policy strategies such as energy efficiency measures and renewable energy application were introduced and increased from the LCM to the more aggressive GO scenarios. We find that the high energy and greenhouse emission under the REF scenario, can be substantially reduced through policy intervention applied in the analysis. A cost benefit analysis was also carried out to ascertain the cost and benefits associated with the implementation of the selected energy policies.

© 2016 The Author(s). This open access article is distributed under a Creative Commons Attribution (CC-BY) 4.0 license. This article has been retracted. Please see Retraction Statement (http://dx.doi.org/10.1080/23311916.2017.1300981)
1. Introduction

In the last century, the world has metamorphosed and experienced a phenomenal transition in the way energy is used, from coal-based to petroleum-based. Ever-increasing globalisation and industrialisation have exponentially increased the demand for energy worldwide (Suganthi & Samuel, 2012). To cope with this exponential increase in demand for energy, energy production has proportionately increased to such an extent that approximately 80% of global energy supply comes from fossil fuel (Biró, 2008). The increase in dependence on fossil fuels has resulted in an increase in global greenhouse gas emissions, which has raised issues about the sustainability of our environment due to tribulations such as climate change and the depletion of natural resources (van Ruijven et al., 2008).

Energy consumption has been one of the most unswerving indicators of development and quality of life attained by any country, and the necessity of satisfying a forecasted energy demand for a given period of time is the key rationale for energy planning (Cormio, Dicorato, Minoia, & Trovato, 2003). As defined by the World Energy Council, “Energy planning is that part of economics applied to energy problems, taking into account the analysis of energy supply and demand, as well as implementation of the means for ensuring coverage of energy needs in a national or international context” (Dictionary, 1992). Researchers around the world have employed different energy models to address policy and planning concerns of energy, economy, and the environment (Pandey, 2002).

Access to clean energy is unreliable and has high disruption costs, affecting production efficiency and competitiveness in many developing countries in Africa and Southeast Asia (Emodi & Yusuf, 2015). Despite being gifted with the widest possible range of energy resources, the African continent has experienced a relatively low energy consumption in general, and electricity consumption in particular (Mayo, 2012). Nigeria, in particular, is experiencing a remarkable paradox—the abundance of energy resources and widespread energy poverty. About 40% of the population have access to the grid electricity supply, while 70% depend on firewood even to this day (Eléri, Ugwu, & Onuvae, 2012). This dependence on firewood constitutes a major indoor pollution hazard and has resulted in the death of nearly 79,000 Nigerians due to smoke inhalation in 2011 (Eléri & Onuvae, 2011). According to a study by the WHO in 2013, the deaths caused by smoke inhalation from firewood used by women has reached 1,000,000 (Emodi & Boo, 2015a).

The Nigerian government’s response to the issue of energy poverty has been to increase the number of gas power plants for electricity generation (Emodi & Boo, 2015b), while plans are still in progress to introduce other sources of energy. The plans are being set up by the Energy Commission of Nigeria (ECN), a government agency which is responsible for the strategic planning and coordination of national energy policies in all its various forms in Nigeria (ECN, 2015). The ECN carried out a study to ascertain the projected future energy demand and supply in some scenarios. This study was carried out using the Model for the Energy Supply Strategy Alternatives and their General Environmental Impact (MESSAGE), and the results are included in the current National Energy Master Plan (Emodi & Boo, 2015c).

Besides the study carried out by the ECN, few studies has over the years consider the bottom-up energy modelling approach to analyse a pathway to a low-carbon development in the Nigerian context. Applying a bottom-up approach in a scenario analysis enable the inclusion of important socio-economic variables such as population, income, household size, technology, energy prices, and the consideration for minimum cost options. The application of scenario analysis enable researchers to explore the impact of future energy policy implementation strategies as these policies have the capacity to alter future energy consumption. Further, the contribution of GHG emission to climate change cannot be left out when carrying out energy modelling because this has a direct impact on the society. The effect of climate change can be observed in almost all parts of Nigeria, and as such the consideration of GHG reduction is important.
Our study is an attempt to address the following pertinent questions which would steer forward energy policy reforms in Nigeria in years to come: (a) What is the projected energy demand in Nigeria and how can this demand be met efficiently at minimum cost without increasing GHGs? (b) Which sustainable energy policy option can be recommended to ensure that low-carbon development is realised in Nigeria? The study aims to answer the research questions by using the Long-Range Energy Alternatives Planning (LEAP) system.

It is anticipated that this investigation will present an opportunity for Nigeria to select from various renewable energy options, low-carbon technologies, and energy efficiency tools to moderate growth in energy demand. This study also intends to provide vital energy policy recommendations for the Nigerian government and energy policy experts to strengthen planning for the future energy systems in Nigeria. This study, however, does consider the ability of consumers to pay for energy services or explore the effect of energy pricing. The scope of this study lies within the range of projected energy demand, supply, and its accompanying GHGs reductions, while briefly projecting the social cost of each policy scenario in the Nigerian LEAP model.

The rest of the paper is organised as follows: Section 2 describes the methodology used in this study elaborating the model, formulation of policy scenarios, and the relevant data used with the source; the results and discussion of the scenarios developed are presented in Section 3; and Section 4 concludes the paper with recommended policy implications based on our study.

2. Methodology, data and scenario development

2.1. The model

The LEAP system (Heaps, 2012) is an integrated modelling tool used for energy policy analysis and climate change mitigation assessment (Stockholm Environment Institute, 2008). It was developed by the Stockholm Environment Institute, and can be used to develop various scenarios of projected energy demand and environmental impact based on how energy is consumed, transformed, and generated in a given nation or economy under a range of values for parameters such as population increase, gross domestic product, income, etc. (Cai et al., 2008). The LEAP model has a flexible data structure which is not only easy to use, but also rich in technical and end-user details (Heaps & Kollmuss, 2008). It has been extensively adopted in many organisations on the local, national, and international levels to project energy supply and demand, predict environmental impact of energy policies, and identify possible challenges in the future.

2.2. The algorithm of the LEAP model

The LEAP model uses a framework for calculating energy consumption, transformation (electricity generation, oil refinery, charcoal production, coal mining), and carbon emissions. These are presented in the following sections.

2.2.1. Energy consumption

The total final energy consumption is calculated as follows (Feng & Zhang, 2012):

\[
EC_n = \sum_i \sum_j AL_{n,j} \times EI_{n,j}
\]  

(1)

where EC is the aggregate energy consumption of a given sector, AL is the activity level, EI is the energy intensity, n is the fuel type, i is the sector, and j is the device.

The net energy consumption for transformation is calculated as follows:

\[
ET_s = \sum_m \sum_t ETP_{t,m} \times \left(\frac{1}{f_{t,m,1}} - 1\right)
\]  

(2)
where ET is the net energy consumption for transformation, ETP is the energy transformation product, \( f \) is the energy transformation efficiency, \( s \) is the type of primary energy, \( m \) is the equipment, and \( t \) is the type of secondary energy.

The transport stock turnover is calculated as follows:

\[
EV_n = \sum_c s \times \frac{m}{fe}
\]

where \( EV \) is the energy consumption in the transport sector, \( s \) is the number of vehicles (stock), \( m \) is the vehicle distance, \( fe \) is the fuel economy, \( n \) is the fuel type, and \( c \) is the vehicle type.

### 2.2.2 Transformation

The transmission and distribution module calculations take the domestic fuel requirement faced by the module and map those corresponding to the output fuels directly to the module input fuels. The total domestic requirements are then decreased by the outputs of the module and increased by the inputs to the module (Lazarus, Heaps, & Raskin, 1997):

For each process \( p \):

\[
\text{INPUT}_p = \frac{\text{OUTPUT}_p}{\text{EFFICIENCY}_p}
\]

For a transmission and distribution module:

\[
\text{EFFICIENCY}_p = 1 - \text{LOSSES}_p
\]

where \( \text{INPUT} \) is the fuel or feedstock, \( \text{OUTPUT} \) is the electricity generated or the refinery/production output, \( \text{EFFICIENCY} \) is the efficiency of the power plants or refinery plants.

### 2.2.3 Carbon emission

The carbon emission from final energy consumption is calculated as follows (Feng & Zhang, 2012):

\[
CEC = \sum_i \sum_j \sum_n AL_{nj}\times EI_{nj}\times EF_{nj}
\]

where \( CEC \) is the carbon emission, \( AL \) is the activity level, \( EI \) is the energy intensity, and \( EF \) is the carbon emission factor from fuel type \( n \) for equipment \( j \) from sector \( i \).

The carbon emission from energy transformation is calculated as follows:

\[
CET = \sum_s \sum_m \sum_t ETP_{tm}\times \frac{1}{ETP_{tm}} \times EF_{tms}
\]

where \( CET \) is the carbon emission, \( ETP \) is the energy transformation product, \( f \) is the energy transformation efficiency, and \( EF \) is the emission factor from one unit of primary fuel type \( s \) consumed for producing secondary fuel type \( t \) through equipment \( m \).

### 2.2.4 Costs

The total cost of sector is calculated (Webmeets, 2015):

\[
C = \sum_i \sum_j \left\{ \left[ \sum_n (e_{nij} + mp_k + fc_{jij}) \right] p_{jij} \right\}
\]

where \( C \) is the total cost of sector including equipment fixed costs and variable costs for raw materials and fuels, \( e_{nij} \) is the unit price of fuel type \( n \), \( mp_k \) is the demand for raw material \( k \) per unit of production used in equipment \( j \) within production process \( i \), \( mp_k \) is the unit price of raw material \( k \), and \( fc_{jij} \) is the fixed cost per unit production through equipment \( j \) (within production process \( i \)).
2.2.5. Cost-benefit analysis

The cost-benefit analysis in LEAP calculates the costs of each part of the energy system, such as the capital and operating maintenance costs of purchasing and using the technologies in the Demand and Transformation systems; the costs of extracting primary resources and importing fuels; and the benefits from exporting fuels. Additionally, one can optionally broaden the scope of the cost-benefit calculations to examine environmental externalities by assigning costs to the emission of pollutants and any other direct social and environmental impacts of the energy system. LEAP performs cost-benefit calculations from a societal perspective by counting the costs in the energy system and then comparing the costs of any two scenarios (Webmeets, 2015).

2.3. Scenario development and assumptions

The scenarios to be formulated are based on the Nigerian government’s planned expansion of electricity capacity, energy services, and proposed mitigation options for the reference (REF) scenario. Much of the formulation in the REF scenario is available in the National Energy Master Plan (ECN, 2015). This research used the REF scenario as a benchmark for the development of three alternative scenarios, which are low-carbon moderate (LCM), low-carbon advanced (LCA), and green optimistic (GO). The REF scenario represents the base case without any energy policy intervention. The alternative scenarios, on the other hand, have had their policy strategies increased in degrees ranging from the LCM with moderate policies, to a more aggressive LCA scenario, and finally the GO scenario, which has a high level of renewable energy application on both the demand and supply side. The summary of the key assumption parameters and features of each scenario used in the Nigerian LEAP model are presented in Tables 1 and 2.

The Nigerian LEAP model is divided into two main branches (see Figure 1): the demand branch and the supply branch. The demand branch is made up of households, industry, commercial services, agriculture, and the transport sector. The household is further divided into urban and rural households which represent the current household situation in Nigeria. The households include various household appliances that are common in Nigerian households. The rural and urban households were further divided into electrified and non-electrified as stipulated by the National Bureau of Statistics (2015). The transport sector was also classified into six vehicle categories which include motorcycles, cars, light goods vehicles, heavy goods vehicles, urban buses, and long distance coaches. On the supply branch, the transformation sector was divided into transmission and distribution (for electricity

---

### Table 1. Key assumption parameters for the Nigerian LEAP model under the REF, LCM, LCA, and GO scenarios

| Key assumption | REF** | LCM | LCA | GO |
|----------------|-------|-----|-----|-----|
|                | 2010  | 2040| 2010| 2040| 2010| 2040| 2010| 2040|
| GDP (million USD) | 369   | 1,255* | 369 | 1,476* | 369 | 1,587* | 369 | 2,177* |
| GDP growth rate (%) | 8     | 10  | 11  | 13  | 8   | 10  | 11  | 13  |
| Income (thousand USD) | 2,310 | 5,705 | 2,310 | 5,914 | 2,310 | 6,329 | 2,310 | 6,676 |
| Income growth rate (%) | 4.9   | 5.2 | 5.8 | 6.3 | 4.9 | 5.2 | 5.8 | 6.3 |
| Population (million) | 160   | 304 | 160 | 318 | 160 | 328 | 160 | 337 |
| Population growth rate (%) | 2.55  | 3   | 2.55 | 3.30 | 2.55 | 3.40 | 2.55 | 3.70 |
| Households (million) | 37    | 72  | 37  | 80  | 37  | 84  | 37  | 87  |
| Household size (people) | 5     | 5   | 5   | 5   | 5   | 5   | 5   | 5   |
| Household growth rate (%) | 3.16  | 3.9 | 3.9 | 3.9 | 4.2 | 4.2 | 4.2 | 4.5 |
| Urbanization rate (%) | 44    | 70  | 44  | 75  | 44  | 80  | 44  | 73  |
| Industry growth rate (%) | 6     | 6.5 | 6   | 7.1 | 6   | 7.5 | 6   | 7.7 |
| Commercial/services growth rate (%) | 12   | 12.5 | 12  | 13.2 | 12  | 13.6 | 12  | 13.9 |
| Agriculture growth rate (%) | 6     | 6.5 | 6   | 7.3 | 6   | 7.4 | 6   | 7.8 |

*Denotes billion.

**The figures in the REF scenario are based on the NEMP 2014.
Table 2. Summary of the features in each scenario

| REF | LCM | LCA | GO |
|-----|-----|-----|-----|
| Driving philosophy | Follows the government’s most-likely-developmental-pathways for the energy system | Driven by cheaper capital, cost, readily available fuels to improve power supply, and moderately reduce energy demand | Motivated by a cleaner fossil fuel power technologies and an aggressive reduction in energy demand | Based on a low-carbon-green growth economy in view of mitigating global climate change, reduce energy poverty, and ensure energy sustainability |

Scenario characteristic

| REF | LCM | LCA | GO |
|-----|-----|-----|-----|
| Current trend of energy consumption continues in all sectors | Moderate improvement in energy efficiency in all sectors | Aggressive improvement in energy efficiency in all sectors | Provision of Energy efficiency and solar PV systems for the demand side |
| No supply side diversification of energy source (BAU case) | Increase in gas power plants, small share of renewables | Introduction of LPG fuel options in addition to biofuel to complement conventional fuels in the transport sector | Phase-out incandescent bulbs and replace with CFL 60% & LED 40% |
| Household cooking fuels are mainly firewood & kerosene | Improved reduction in electrical and natural gas losses | Introduction of LPG fuel options with a reduced share of conventional fuels | Reduction in the share of fossil fuel plant capacity and the increase share of renewables on the supply side |
| Household source for lighting are electricity from national grid & kerosene | Household cooking fuels are mainly kerosene & charcoal | Improved reduction in electrical and natural gas losses | CNG, LPG and biofuel options to complement conventional fuels in the transport sector |

General assumptions

| REF | LCM | LCA | GO |
|-----|-----|-----|-----|
| Increased electricity access to 100% by 2030 | Demand side: CFL introduction, moderate energy efficiency in appliances | Demand side: LED introduction, aggressive energy efficiency in all sectors | Demand side: introduction of both CFL and LED with reduction in incandescent bulbs, advance approach towards energy efficiency in all sectors |

Scenario-specific assumptions

| REF | LCM | LCA | GO |
|-----|-----|-----|-----|
| Supply side (electricity): Installed capacity by 2040 = 155,283 MW | Supply side: Installed capacity by 2040 = 170,500 MW | Supply side: Installed capacity by 2040 = 180,500 MW | Supply side: Installed capacity by 2040 = 181,000 MW |
| Estimated share of fuel type (electricity): | Estimated share of fuel type: | Estimated share of fuel type: | Estimated share of fuel type: |
| Fossil fuel = 90% | Fossil fuel = 80% | Fossil fuel = 60% | Fossil fuel = 30% |
| Renewables = 10% | Renewables = 20% | Renewables = 40% | Renewables = 70% |
| Estimated share of fuel for transport sector by 2040: | Estimated share of fuel for transport sector by 2040: | Estimated share of fuel for transport sector by 2040: | Estimated share of fuel for transport sector by 2040: |
| Petrol = 60% | Petrol = 40% | Petrol = 30% | Petrol = 10% |
| Diesel = 40% | Diesel = 20% | Diesel = 10% | Biofuel = 30% |
| Biofuel = 20% | Biofuel = 30% | LPG = 30% | CNG = 30% |
| Transmission & Distribution loss by 2040 = 6% | Transmission & Distribution loss by 2040 = 6% | Transmission & Distribution loss by 2040 = 5% | Transmission & Distribution loss by 2040 = 5% |
and natural gas), electricity generation, charcoal production, oil refining, and coal mining. The resources branch under the transformation sector includes primary and secondary resources.

2.4. Data source

The required data and their various sources are presented in Table 3.

| Table 3: data source                                      |
|----------------------------------------------------------|
| **Data**                                                 | **Source**                                                                 |
| GDP, GDP per capita, GDP growth rate, population, population growth rate, urban and rural population/percent, industry and transport value added | The World Bank Development Indicators. www.worldbank.org |
| Selected population growth                               | National Population Commission, National Bureau of Statistics |
| Household size and characteristics                        | National Bureau of Statistics. http://www.nigerianstat.gov.ng |
| Agriculture and commercial sector                         |                                                                         |
| Industry and transport sector energy consumption           | International Energy Agency (2011)                                      |
| Industrial electricity and household supply               | International Energy Agency, Central Bank of Nigeria Statistical Bulletin |
| Transport sector characteristics                          | Nigeria Vision 2020 National Technical Working Group on Transport       |
| Electricity sector characteristics (generation, transmission, capacity factor, historical production) | National Control Center Osogbo Generation and Transmission Grid Operation Annual Technical Report 2010, Federal Government of Nigeria Roadmap for Power Sector Reform 2010 |
| Government energy/electricity demand and supply projection | National Energy Policy (2013), National Energy Master Plan (2014)         |
| Emission factors                                          | IPCC guidelines for national GHG inventories                            |
| Government renewable energy and energy efficiency plan    | National Renewable Energy and Energy Efficiency Policy (2014)            |
| Greenhouse gas emissions from energy consumption and electricity generation | 2006 IPCC guidelines for national GHG inventories |
As shown in Table 3, most of the data used in the scenario development were based on government documents, while the alternative scenarios were based on assumptions of the best possible approach to low-carbon development in Nigeria.

3. Results and discussion

3.1. Results

3.1.1. Energy demand

Based on the assumptions about the socio-economic development in Nigeria and various parameters presented in Tables 1 and 2, the values of total energy consumption the Nigerian LEAP model for the REF, LCM, LCA, and GO scenarios from 2010 to 2040 are shown in Figure 2. In general, energy consumption will increase steadily up to 2040 under each scenario, but with different growth rates. The energy consumption in the REF scenario is expected to reach 3,075 PJ by 2040, from 1,039 PJ in 2010, with an annual growth rate of 3.68%, the highest amongst the four scenarios. Much of the energy consumed in the REF scenario in the base year comes from the household sector with a share of 40%, which is followed by the industry (29%), and transport (22%). This, however, made a slight shift in 2040 with an increase in the household and commercial/service sector, while reduction was observed in the industry and transport sector.

Due to the series of energy efficiency improvements and fuel and technology switching, the total energy consumption will be lower under the alternative scenarios. The LCM scenario energy consumption is reduced to 2,941 PJ with an annual growth rate of 3.53%. As can be recalled from Table 2, the moderate improvement in the demand sector was energy efficiency measures such as the replacement of 70% incandescent bulbs with CFL bulbs. The more aggressive energy policies in the LCA scenario led to the decrees in energy consumption to 2,488 PJ at a growth rate of 2.95%. The household sector saw its share reduced, while the transport sector share of energy consumption increased due to the introduction of LPG for the transport sector (Figure 3).

The GO scenario, which has a higher level of renewable energy application such as solar PV and efficient use of firewood for the household, had a reduced total energy consumption of 2,249 PJ at a growth rate of 2.61%. As observed in Figure 3, the household had a slight reduction in energy consumption under the GO scenario.
consumption compared to the LCA scenario, which is due to the phase-out of incandescent bulbs, efficient bulbs, and the provision of solar PV to reduce energy demand.

3.1.2. Final energy use by fuel

The structural changes in the final energy usage in 2020, 2030, and 2040 are shown in Figure 4 for the four policy scenarios. Under the REF scenario, the energy usage structure will remain almost the same as that in 2010, with a slight increase in electricity consumption to 19%. Biomass, kerosene and gasoline will still dominate the Nigerian energy consumption system by 2040 under the REF scenario. In contrast, under the alternative scenario, the proportion of kerosene consumption will decrease to 23% in the LCM, 21% in the LCA, and 20% in the GO scenario. The decrease of kerosene use in the alternative scenario is seen as a result of energy efficiency improvements in cooking technology (efficient kerosene cooking stoves) and provision of alternative fuel options.

The share of gasoline decreased in the alternative scenarios from LCM (11%) to LCA (10%), while the GO had 9% gasoline use due to the increased popularity of CNG (4%) and LPG (10%) as alternative fuel options for the transport sector. Moreover, the share of clean energy usage, including electricity, LPG, CNG (in the GO), and natural gas will increase rapidly across the alternative scenarios, eventually more than 50% by 2040. Overall, under the LCA and GO scenarios, the energy usage structure will gradually become environmentally friendly in Nigeria, with rapid growth in alternative clean energy. This will play an important role in the realisation of a low-carbon development in Nigeria and GHG mitigation.
3.1.3. Electricity production

To meet the growing demand for electricity, the REF scenario assumes an expansion in electricity generation capacity to be able to generate 179,000 MWh by 2040, as shown in Figure 5. The electricity mix under the Nigerian government REF scenario by 2040 will include 36% of power generation coming from single cycle gas turbine (SCGT) and 18% from combine cycle gas turbine (CCGT) for on-grid electricity supply, while 18% will be generated from off-grid diesel generators. The contribution of renewable energy technologies is low when compared to the alternative scenarios, especially the LCA and GO scenarios.

The LCA scenario had an electricity supply of 184,000 MWh from the combination of power plants, which comprises 60% fossil fuel and 40% renewables by 2040. The reduction in the number of SCGT power plants (7%) and the increase in CCGT share will contribute to improved efficiency of gas power plants, since CCGT is more efficient than SCGT. Other fossil fuel power plants with lower emissions include coal integrated gasification combine cycle (IGCC) and circulating fluidised bed (CFB), with shares of 8 and 9% respectively (Figure 6).

Meanwhile, renewable energy technologies will include large hydropower (9%), biomass (5%), onshore wind (2%), and solar thermal and PV systems at 2% each for on-grid power supply as shown in Figure 6. The mix is further improved with an increased share of renewable power generation of about 70% in the GO scenario. This was intended to increase electricity generation from clean and sustainable sources, while reducing GHG emission levels by 2040.

3.1.4. Greenhouse gas emission

The GHG emission from energy consumption under the four scenarios from 2010 to 2040 is shown in Figure 7. Under the REF scenario, GHG emissions will increase from 50.2 million metric tons of CO₂ equivalent (Mt Co2e) in 2010 to 201.2 Mt Co2e in 2040, with an annual growth rate of 4.74%. The rate of GHG emission can be correlated directly to the level of energy consumption as observed in the REF scenario (compared with Figure 2), and for the LCM at 185.4 Mt Co2e. Under the LCA, emissions will increase to 152 Mt Co2e in 2040 at a significant growth rate of 3.87%, which is in line with the total energy consumption trend predicted for the LCA in Figure 3. However, under the GO scenario, the emission will reach a peak value of 124.4 Mt Co2e in 2040.
The turning point in the GHG emission pathways in the LCA from 2030 may be due to the optimisation of the energy structure. Furthermore, energy intensive sectors such as the iron and steel industries in the GO scenario will experience technology switching, while electricity usage will be increased in all sectors to reduce fossil fuel consumption. On the supply side, the increased use of renewable energy in the GO scenario also contributed to the reduction in GHG emissions as can be observed in Figure 7. This means that to achieve low-carbon development in Nigeria, the introduction and deployment of clean energy technologies should not only focus on demand but also on supply.

3.1.5. Cost-benefit analysis
The results of the cost-benefit analysis for the scenarios analysed in this study are presented in Table 4, which also highlights net present value (NPV) of alternative scenarios relative to the REF scenario. NPV represents all discounted costs and benefits in one scenario minus another.

From Table 4, we can observe that under the demand variable (or demand side), the cost for the implementation of the LCM scenario is USD 36.62 million, while LCA and GO scenario was USD 31.32 and USD 30.61 million respectively. In implementing the policies in the LCM scenario, USD 2.73
million will be saved by the Nigerian government (as benefit), while USD 38.93 million would have been spent in achieving the policies in the transport sector and USD 42 million in the households sector. In the LCA scenario, more would be spent for households' energy efficiency policies (USD 560 thousand), while USD 38.11 million will be spent in the transport sector.

Costs in the transport sector will include the introduction and increase of LPG vehicles, energy efficiency, and fuel switching. The transformation sector showed various levels of costs which varied across scenarios. The LCM scenario had a lower cost in terms of implementing the strategies, while LCA had a higher cost of USD 36.12 million. Environmental externalities presented a benefit in all the alternative scenarios, with the GO scenario having the most benefit of USD 34.48 million, followed by the LCA scenario with a benefit of USD 24.05 million. The overall NPV for the alternative scenarios are USD 1.69 billion for the LCM, USD 23.8 billion for the LCA, and USD 41.4 billion for the GO scenario. This overall NPV is the cost of how much more the alternative scenario costs vs. the REF scenario. Lastly, the cost of avoided GHG emissions was higher in the LCA (USD 71.8/TCDE) scenario, than in the GO (USD 43.4/TCDE). The reason for the lower cost avoided GHG emission was due to the costs saved in the industry (~2.35 million), commercial service (~9.56 billion) as compared with the LCA scenario. Costs were also saved from the production of energy from natural resources (~303.14 million) and Environmental externalities (~34.48 million) in the GO scenario, since more renewable energy resources were utilized than fossil fuel resources.

| Table 4. Results of the cost-benefit analysis |
|------------------------------------------------|
| Cumulative costs and benefits: 2010–2040. Relative to scenario: Reference |
| Discounted at 5.0% to year 2010. Units: Billion 2010 USD |
| LCM | LCA | GM |
| Demand | 36,062,000 | 31,032,000 | 30,061,000 |
| Households | 42,000 | 56,000 | 57,000 |
| Industry | - | -1,061,000 | -2,035,000 |
| Commercial_service | -2,073,000 | -5,074,000 | -9,056,000 |
| Agriculture | - | - | - |
| Transport | 38,093,000 | 38,011,000 | 41,095,000 |
| Transformation | 15,065,000 | 36,012,000 | 81,062,000 |
| Transmission and distribution | - | - | - |
| Electricity generation | 15,065,000 | 36,012,000 | 81,062,000 |
| Charcoal production | - | - | - |
| Oil refining | -2,073,000 | -5,074,000 | -9,056,000 |
| Coal mining | - | - | - |
| Resources | 1,640,019,000 | 23,790,023,000 | 41,269,017,000 |
| Production | -209,043,000 | 44,014,000 | -303,014,000 |
| Imports | 1,849,062,000 | 23,746,009,000 | 41,572,031,000 |
| Exports | - | - | - |
| Unmet requirements | -4,002,000 | -24,005,000 | -34,048,000 |
| Environmental externalities | -4,002,000 | -24,005,000 | -34,048,000 |
| Non energy sector costs | - | - | - |
| Net present value | 1,688,044,000 | 23,833,061,000 | 41,346,092,000 |
| GHG savings (Mt CO2e) | 221,073,000 | 332,014,000 | 952,000,000 |
| Cost of avoiding GHGs (USD/TCDE*) | 7,615,000,000 | 71,757,093,000 | 43,431,071,000 |

*TCDE: Tonne per carbon dioxide equivalent.
3.2. Discussion

As a signatory to the UNFCCC and Kyoto Protocol, Nigeria will have to make international commitments in promoting low-carbon development by meeting its reporting obligation to the UNFCCC and reducing greenhouse gases (GHG) emissions within the context of poverty reduction and economic growth (Eleri, Onuvae, & Ugwu, 2013). Among the four policy scenarios, the alternative scenarios will achieve some improvement in energy and GHG reduction. Under the LCA and GO scenarios, the emission will be 7 and 11% lower than the REF scenario by the end of 2040. Obviously, the GO scenario shows a more favourable development trajectory towards low-carbon development for Nigeria, demonstrating that more carbon emission reductions are possible by implementing additional policies and strategies. Thus, specific measures can be recommended for certain sectors of Nigeria’s economy to achieve and sustain low-carbon development.

For the households or residential sector, the emphasis should be on improving the efficiency of energy technologies such as kerosene, charcoal, and firewood cooking devices. The ECN stressed the need for the massive deployment of these efficient cooking stoves for the Nigerian households in its national energy policies, but efforts to popularise the energy technologies have been slow. To complement this, LPG and solar cookers should be introduced into the household energy mix. Agbo and Oparaku (2006) highlighted some pressing policy issues preventing the deployment of these energy technologies and alternative fuels including poor research and development (R&D), pilot and demonstration projects, institutional framework, investment promotion, incentives, and protections.

However, if the Nigerian government intends to achieve a reduction in energy demand and GHG emissions as observed in the LCA and GO scenarios, these challenges need to be addressed. On improving the efficiency of household electrical appliances, the emphasis should be on implementing energy standards for refrigerators, air conditioners, and electric stoves; and more importantly, phasing out incandescent bulbs and replacing them with LED and CFL bulbs.

Some measures, such as “Phase out Incandescent Light Bulbs” (POILB), should be employed. Many countries around the world have employed this policy measure including China, which started the ban in 2007 but extended it to 2016; India, which also started the ban on incandescent bulbs in 2012; Israel has been phasing out incandescent bulbs since 2012; the United Kingdom in 2011; and all European Union (EU) countries have until 2016 to completely phase-out incandescent bulbs before 2016. Other countries include Canada, who made a move in 2007, while most states in the United States (US) have completely phased out incandescent bulbs since 2007 and others will phase in 2018. Some countries implemented new energy standards and phased out incandescent bulbs like Argentina in 2012 and Mexico, Malaysia, and South Korea in 2014. The Nigerian government can also stimulate the residential sector to improve household efficiency through the provision of subsidies for consumers who purchase and use efficient appliances, as well as renewable energy sources such as solar thermal and PV systems.

For the commercial/service sector, similar policy scenario for the household sector holds for electrical appliances and lighting bulbs. Furthermore, the provision of adequate electricity supply will ensure the proper shift towards the use of electricity as final energy consumption, instead of fossil fuels such as diesel, gasoline, biomass, etc. The same stimulus policy for efficiency improvement and renewable energy integration in the demand side will aid in the transition toward low-carbon development. Public services, such as hospitals, will now have a means of building a sustainable and unlimited power supply to carry out their social duties, while reducing the need for dependence on diesel and gasoline for private power generation.

For the industrial sector, optimisation of the production structure and improvement in energy efficiency are vital in achieving low-carbon development. This can be promoted by energy auditing in industries, as in the study carried out by Sunday Olayinka and Thomas Oladele (2013). In their study, they found out that consumption by electric motors accounts for 40–47% of the total electricity consumed in most industries in Nigeria. Others, such as boilers and heaters, account for 65% of the
total energy consumed. The inefficiencies in energy use were attributed to poor housekeeping of air conditioners, refrigeration equipment, wheel electric motors, and lack of switching off electric bulbs during the day. These inefficiencies, if addressed, will result in the reduction of about 30% of energy demands in the industrial sector.

In addition, electric arc blast furnaces for iron and steel industries should replace the conventional ones by 2040. The introduction of these furnaces has great potential for the reduction of energy/electricity consumption and GHG emissions due to their high level of energy efficiency. This technology switching will increase the share of electricity in the industrial final energy mix, while reducing fossil fuel consumption. The implementation of this policy on a short timescale may be difficult, but can be tackled through the provision of financial incentives, subsidies, and tapping into global energy-saving funds such as clean development mechanism (CDM) and global climate funds (GCF) to help promote the industrial transformation.

For the transport sector, the use of public transport systems such as the bus rapid transport (BRT) system already in Lagos, Nigeria and light rail in some parts of Nigeria should be encouraged and popularised by the Nigerian government. The implementation of alternative vehicle fuels such as CNG, LPG, and biomass will reduce the dependence on high GHG-emitting gasoline and diesel fuels. The South Korean BRT system is comprised of mainly CNG-powered buses. This move was to ensure a reduction in GHG emissions. In the Korean transport sector, LPG is another alternative fuel besides CNG that is intended to provide consumers with low GHG-emitting fuel options. The LCA and GO scenarios proved that this could be replicated in the Nigerian transport sector if the government is ready to implement some policies such as the Autogas Incentive Policies (AIP) to stimulate commuters. The AIP has contributed to the increased use of LPG for transportation in most countries around the world.

In terms of the energy supply sector, the reduction in T&D losses should be promoted for the electricity sector as well as natural gas supply, which is used to power SCGT and CCGT power plants. However, the Nigerian government should encourage construction of CCGT power plants over SCGT, which is less efficient. For coal power plants, more efficient combustion technologies such as IGCC, CFB, and supercritical should be given more preference over the conventional coal steam power plants. Although coal power plants are higher GHG-emitting energy technology, great potential exists for carbon capture and storage (CCS) technology in future. The Nigerian government should focus more on development of nuclear and renewable energy sources, which are low-carbon technologies that are vital for the attainment of a low-carbon development before 2040.

The government can increase the capacity of nuclear power plants to contribute more to the electricity mix as observed in the LCA and GO scenarios, instead of the small share in the REF scenario. This should be matched with renewable sources such as solar, wind, hydro, biomass, and geothermal. This actually disproves the Ibitoye (2013) study, where his bottom-up approach using the LEAP model suggested that the most likely development pathway for Nigeria to generate electricity to meet the millennium development goals (MDGs) was through natural gas alone. This study, therefore, provides electricity generation alternatives that will not only meet the increasing energy demand, but also with lower GHG emissions due to using sustainable energy resources.

Although this study applied a bottom-up approach to project the pathway for the complete energy system in Nigeria, great care should be taken to understand the term “low-carbon development” in the Nigerian context. According to the Conference of Parties to the UNFCCC, the concept of low-carbon development strategies (LCDS) is a common but differentiated approach to meet the overall emissions reduction objectives: “All countries shall prepare Low Emission Development Strategies...nationally-driven and representing the aims and objectives of individual Parties in accordance with national circumstances and capacities” (Cancun Agreement). This means that for a developing country like Nigeria, the path towards low-carbon development should be based on the nation’s circumstances and ability to go the extra mile in attaining a low-carbon economy. However, “low-carbon” is a futuristic development that must be pursued, not necessarily as the goal, but...
rather to test our efforts towards low-carbon development. The low-carbon developmental pathway in Nigeria is not static, but dynamic; therefore it needs to be constantly amended at different stages and periods in time. This study provides some likely developmental pathways through the developed scenarios for the Nigerian energy system, and explored the impact of future energy policies and strategies that will be required on the path to a low-carbon transition.

4. Conclusions and policy implications
In this study we developed an energy model for Nigeria which considered vital factors capable of influencing energy policies in future. The four scenarios developed in the model include a reference scenario and three alternative scenarios. The alternative (LCM, LCA, GO) scenarios were influenced with various levels of policies and strategies to check different low-carbon development pathways for Nigeria from 2010 to 2040 using the LEAP modelling tool. The results showed that the strategic policies implemented in the Nigerian LEAP model will have a significant impact on energy consumption and GHG emissions.

Under the REF scenario, energy demand in 2040 will be 3,075 PJ, with a growth rate of 3.68% with a corresponding increase in GHG emissions of 201.2 Mt CO2e. Policy scenarios such as the LCM, LCA and GO scenarios had lower energy demands of 3.53, 2.95 and 2.61% respectively. Similarly, GHG emissions were generally reduced across the policy scenarios. To achieve such large reductions in energy demand and GHG emissions, strategic policies and technological switching is not enough, although they contributed to the reduction in energy consumption and GHG emissions in Nigeria. The Nigerian government will need to do more to promote low-carbon energy technologies and energy efficiency measures through policy interventions and incentives.

Since the focus of this study was to transit Nigeria towards a low-carbon economy, the optimisation of the energy structure was focused on shifting from fossil fuel to clean energy, as in the LCA and GO, which will play a significant role in GHG reduction in Nigeria. The cost-benefit analysis results showed that the implementation of the policies in the LCM will amount to a cost of USD 1.69 billion, the LCA policy will cost USD 23.8 billion, while the GO policies will cost USD 41.1 billion. Although the costs are high due to investments in energy efficiency, fuel switching, etc., these costs are somewhat offset by the energy savings on the demand side, production, and environment externalities. Overall, the household and transport sector are key areas for low-carbon development in Nigeria, while the industrial and commercial/service sectors also hold great potential in the reduction of energy consumption and GHG emissions in the coming years.

In conclusion, for Nigeria to achieve low-carbon development, it is important for the country to explore various policy options relevant to the reduction of energy demand and GHG emissions with clean energy resources. However, it is not expected to be easy for Nigeria to achieve low-carbon development, as some challenges cannot be ignored. For example, the deployment of efficient cooking stoves and other clean energy technologies in Nigeria has proved challenging for the government, due to the high cost of the technologies for the consumers on the demand side. On the supply side, the cost of renewable energy is still very high as it requires huge capital investment, and this increases the preference for fossil fuels such as natural gas. This could be addressed if the Nigerian government implements some fiscal incentives such as tax relief and exception for clean energy technology imports, subsidies and loans for the purchase of renewable energy, and public awareness to raise interest on the benefit of clean energy technologies.

Policy implications of the study include: (a) It is important for Nigeria to improve on energy efficiency in both the supply and demand sides through the application of modern energy technologies and practice, as this will have an impact on Nigeria’s future energy conservation and GHG reduction. (b) The government should make provisions for the development and deployment of alternative fuels in the demand and supply sides, as this will reduce dependence on a particular energy source such as biomass or crude oil. (c) The government should make incentives such as investment tax credits, low cost loans for power generation, and increased feed-in-tariff options. (d) The
establishment of energy and environmental policies should support clean energy, as this will accelerate the transition to a low-carbon economy in Nigeria. (e) Low-carbon development should be seen as a step in the right direction, and this should be done according to the ability, capacity, and capability of Nigeria. This research is not without limitation, as some transport variables such as railway, airway, and seaway transport system were excluded due to lack of available data. Additionally, the alternative scenarios do not exhaust the possibility of providing solutions to a low-carbon development in Nigeria. Thus, more policy scenarios can be developed in future studies which will include the complete transport variables and eventually update the present study with further policy implications.

5. This is summed up across all the years of the study; and in this study, it was summed from 2010 to 2040.
6. These strategies include the building and capacity expansion of power plants that are not in the REF scenario. For some power plants in the REF scenario that are in the alternative scenarios, the differences are taken which is the cost of the expanded capacity of the alternative scenario which is the differences between the two scenarios. Please note that the strategies also include the cost of improvement in T&D.

Environmental externalities refer to the economic impact of uncompensated environmental effects of production and consumption that affect consumer utility and enterprise cost outside the market mechanism. As a consequence of negative externalities, private costs of production tend to be lower than its “social” cost. It is the aim of the “polluter/user-pays” principle to prompt households and enterprises to internalise externalities in their plans and budgets (United Nations, 1997).

8. Please note that it is one alternative scenario vs. the REF scenario (i.e. LCM vs. REF, LCA vs. REF, etc.).
9. This is given by dividing the NPV by the TCDE avoided.
10. See www.energysaving.gov.au/products-themes/lighting/lighting-and-phase-out-general-information/incandescent-light-bulbs-phase-out/.
11. www.reuters.com/article/2011/11/05/us-china-light-bulbs-idUSTRE7A460M/20111105.
12. www.treehugger.com/interior-design/india-to-phase-out-400-million-incandescent-light-bulbs-by-2012 replaces-with-cfls.html.
13. www.energy.gov.il/LightBulb/Pages/GxmsMminSite-LightBulb.htm.
14. www.news.bbc.co.uk/2/hi/uk_news/news/7016020.stm.
15. www.greenpeace.org.uk/blog/climate/eu-ban-insufficient-light-bulbs-eventually-sort-20081212.
16. www.reuters.com/article/2007/04/25/us-lightbulbs-env-idUSN252925320070425.
17. www.leginfo.ca.gov/pub/07-08/bill/asm/ab_1101-1150/ab_1109_bill_20070223_introduced.html.
18. www.lanacion.com.ar/1091978-desde-2011-no-podran-vender-se-mas-lamparas-incandescentes.
19. www.yonhapnews.co.kr/economy/2013/07/16/03020000000AKR20130716057151003H-TML.
20. The AIP is promoted by the government through lowering fuel tax vis-à-vis gasoline and diesel, lowering vehicle taxes or conversion subsidies, employing traffic measures, and removing barriers (parking restrictions, etc.).
21. www.bpnews.com/index.php/publications/magazine/current-issue/350-world-autogas-demand-jumps-57-in-post-decades-incentives-play-key-role.
22. Although geothermal energy has not been widely popularised in Nigeria, studies (Nwachukwu, 1976; Avbovbo, 1978; Gelnett & Gardner, 1979; Mosto, Onuoha & Ekine, 1999; and Nwanwko, Olasehinde, & Akoshile, 2009) have analysed various parts of Nigeria for geothermal resources, while Kurowska and Krzysztof (2010) highlighted that the geothermal resources in Nigeria were enough to be exploited for power generation.
23. See http://cancun.unfccc.int/.
Cover image
Source: Author.

References
Agbo, S. N., & Oparaku, O. U. (2006). Positive and future prospects of solar water heating in Nigeria. The Pacific Journal of Science and Technology, 7, 191–198.
Avbovbo, A. A. (1978). Geothermal gradients in the southern Nigeria basin. Bulletin of Canadian Petroleum Geology, 26, 268–274.
Biro, F. (2008). World energy outlook. Paris: International Energy Agency.
Cai, W., Wang, C., Chen, J., Wang, K., Zhang, Y., & Lu, X. (2008). Comparison of CO2 emission scenarios and mitigation opportunities in China’s five sectors in 2020. Energy Policy, 36, 1181–1194.
http://dx.doi.org/10.1016/j.enpol.2007.11.030
Central Expenditure Evaluation Unit. (2013). Guide to economic appraisal: Carrying out a cost benefit analysis. The public spending code. Retrieved August 29, 2015, from www.publicspendingcode.per.gov.uk/wp-content/uploads/2012/08/003-Guide-to-economic-appraisal-CBA-16-July.pdf
Cormio, G., Dicorato, M., Ninoia, A., & Trovato, M. (2003). A regional energy planning methodology including renewable energy sources and environmental constraints. Renewable and Sustainable Energy Reviews, 7, 99–130.
http://dx.doi.org/10.1016/S1364-0321(03)00004-2
David, R., Ngulube, P., & Dube, A. (2013). A cost-benefit analysis of document management strategies used at a financial institution in Zimbabwe: A case study. South African Journal of Information Management, 15(2), 1–11.
Dictionary, E. (1992). Dictionary, E. (1992). Otu-otu, Nigeria.
Eleri, E. O., Onuvae, P., & Ugwu, O. (2013). Low carbon energy development in Nigeria: Challenges and opportunity (The Sunga Report). London: International Institute for Environment and Development (IIED).
Eleri, E. O., Onuvae, P., & Ugwu, O. (2013). Low carbon energy development in Nigeria: Challenges and opportunity (The Sunga Report). London: International Institute for Environment and Development (IIED).
Emodi, N. V., & Boo, K. J. (2015a). Sustainable energy development in Nigeria: Overcoming energy poverty. International Journal of Energy Economics and Policy, 5, 565–573.
Emodi, N. V., & Boo, K. J. (2015b). Decomposition analysis of CO2 emissions from electricity generation in Nigeria. International Journal of Energy Economics and Policy, 5, 565–573.
Emodi, N. V., & Boo, K. J. (2015c). Sustainable energy development in Nigeria: Current status and policy options. Renewable and Sustainable Energy Reviews, 51, 356–381.
http://dx.doi.org/10.1016/j.rser.2015.06.016
Emodi, N. V., & Yusuf, S. D. (2015). Improving electricity access in Nigeria: Obstacles and the way forward. International Journal of Energy Economics and Policy, 5, 335–351.
Energy Commission of Nigeria. (2015). Retrieved July 18, 2015, from www.energy.gov.ng
Feng, Y. Y., & Zhang, L. X. (2012). Scenario analysis of urban energy saving and carbon abatement policies: A case study of Beijing city, China. Procedia Environmental Sciences, 13, 632–644.
http://dx.doi.org/10.1016/j.proenv.2012.01.055
Gelnett, R. H., & Gardner, J. V. (1979). Use of radar for ground water exploration in Nigeria, West Africa. Phoenix, AZ: Motorola Aerial Remote Sensing, Incorporated.
Heaps, C. G. (2012). Long-range Energy Alternatives Planning (LEAP) system (Software version 2015.0.4). Somerville, MA: Stockholm Environment Institute. Retrieved from www.energycommunity.org
Heaps, C., & Kollmuss, A. (2008). UNFCCC resource guide for preparing the national communications of non-Annex I Parties. Module 4: Measures to Mitigate Climate Change. Bonn: Author.
Ibitayo, F. I. (2012). The millennium development goals and households energy requirements in Nigeria. Springer Plus, 2(1), 1–11.
International Energy Agency. (2011). World energy outlook 2011. Paris: Author.
Kowalski, K., & Krzywy, J. S. (2010, April). Geothermal exploration in Nigeria. In Proceedings World Geothermal Congress 2010. Bonn: Author.
Lazarus, M., Heaps, C., & Raskin, P. (1997). Long-range energy alternatives planning system—user guide for version 95. Boston, MA: Stockholm Environment Institute.
Moyo, B. (2012). Do power cuts affect productivity? A case study of Nigerian manufacturing firms. The International Business & Economics Research Journal (Online), 11, 1163. National Bureau of Statistics. (2015). Retrieved from http://www.nigerianstat.gov.ng
National Energy Master Plan. (2014). Energy commission of Nigeria. Retrieved from http://www.energy.gov.ng
National Energy Policy; Draft Revised Edition (2013). Abuja: Federal Republic of Nigeria. Retrieved from www.energy.gov.ng
National Renewable Energy and Energy Efficiency Policy (2014). Energy Commission of Nigeria (ECN) and Federal Ministry of Science and Technology (FMT) Retrieved August 5, 2015, from www.energy.gov.ng
Nwachukwu, S. O. (1976). Approximate geothermal gradients in Niger Delta sedimentary basin. AAPG Bulletin, 60, 1073–1077.
Nwankwo, L. I., Olasehinde, P. I., & Akoshile, C. O. (2009). An attempt to estimate the Curie-point isotherm depths in the Nupe Basin, West Central Nigeria. Global J. Pure Applied Sci, 15, 427–433.
Pandey, R. (2002). Energy policy modeling: Agenda for developing countries. Energy Policy, 30, 97–106.
Spellman, F. R. (2015). Economics for environmental professionals. Boca Raton, FL: CRC Press.
http://dx.doi.org/10.1201/b18345
Stockholm Environment Institute. (2008). User Guide, LEAP: Long range energy alternative planning system. Boston, MA: Author.
