Renewable and Sustainable Energy Reviews 68 (2017) 247–261

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Energy policy for low carbon development in Nigeria: A LEAP model application

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ARTICLE INFO

Keywords:
Energy policy
Scenario analysis
Low-carbon development
Nigeria
LEAP model
Energy forecasting

ABSTRACT

This paper applied a scenario-based analysis to explore Nigeria's future energy demand, supply and associated GHG emissions from 2010 to 2040 using the Long-range Energy Alternative Planning (LEAP) model. The impact of different energy policies are analysed for the Nigerian energy system by considering four scenarios: the reference scenario (REF), the low-carbon moderate scenario (LCM), the low-carbon advanced scenario (LCA), and the green optimistic scenario (GO). 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 and energy system analysis were also carried out in the study.

1. Introduction

During the pre-industrial revolution, the global development was hindered by low energy intensity in the form of hydro and wind resources. The second industrial revolution saw the increase in fossil fuel consumption which lead to electrification and technological commercialization of goods and services [48]. From 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 [43]. 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 (IEA, 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 [47].

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 [7]. 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” [11]. Researchers around the world have employed different energy models to address policy and planning concerns of energy, economy, and the environment [35].

Access to clean energy is unreliable and has high disruption costs, affecting production efficiency and competiveness in many developing countries in Africa and Southeast Asia [18]. 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 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 [13]. 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 [12]. According to a study by the World Health Organization in 2013, the deaths caused by smoke

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http://dx.doi.org/10.1016/j.rser.2016.09.118
Received 10 August 2015; Received in revised form 29 August 2016; Accepted 26 September 2016
1364-0321/

inhalation from firewood used by women has reached 98,000 [15].

The Nigerian government's response to the issue of energy poverty has been to increase the number of gas power plants for electricity generation [16], 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 [19]. 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 [17,30].

However, the study carried out by the ECN missed several important elements: (a) The ECN did not develop scenarios considering various parameters which can influence energy demand. The only parameter considered was economic growth rate (GDP), which is not the only determinant for the increase in energy demand. Other parameters include population, income, household size, technology, energy prices, etc. Also, minimum cost options were not observed in the ECN study. (b) The impact of future energy policy implementation and strategies were not considered in the ECN study. The impact of various energy policies is expected to alter the energy consumption pattern of a country on the short-, medium-, and long-term horizons. Also, incentives such as Feed-in-Tariff may affect energy consumption patterns. (c) The effects of greenhouse gases on the environment were not considered in the ECN study. The contribution of GHGs 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, while Section 4 concludes the paper with recommended policy implications based on our study.

2. Methodology, data and scenario development

2.1. The model

The Long-Range Energy Alternatives Planning (LEAP) system [27] is an integrated modelling tool used for energy policy analysis and climate change mitigation assessment [41]. 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 region or economy under a range of values for parameters such as population increase, gross domestic product, income, etc. [5]. The LEAP model has a flexible data structure which is not only easy to use, but also rich in technical and end-user details [45]. 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.

In the household, commercial, transport and industrial sectors around the world, the LEAP model have been used to assess their energy consumption and greenhouse gas emissions [37]. Studies such as Bose [4] simulated the passenger transport sector for New Delhi city in India, while Shin et al. [39] analysed the impact of expanded land fill gas (LFG) method of electricity generation on cost of electricity generated and GHG emission in South Korea. The environmental and economic assessment of energy policy for South Korea was carried out by Song et al. [40] using the LEAP model. The energy sector in Estonia was modelled for environmental impact of electricity generation from newer, lesser amount of environmental destructive technology using the LEAP model [9]. Furthermore, Huang et al. [22] has elucidated the importance of long-term forecasting of energy supply and demand for Taiwan. Scenarios were developed to present a possible pathway to a low-carbon economy for China in Taoa et al. [44] study, and this low-carbon pathway was further developed in Feng and Zhang [20] study for Beijing. The LEAP has been applied to ascertain the projected direct energy consumption in Nigerian households [23], while it has been used for other African countries such as Ethiopia [38] who developed alternative scenarios for the country's energy requirement up-to 2050. The energy demand and pollutant emissions for the Greek road transport sector was analysed by Bitos and Kiartzis [3] from 2010 to 2035. More recently, Mahumane and Mulder [28] estimated the aggregate trends in energy supply and demand due to projected gush in natural resource exploration in Mozambique. Other studies that have applied the LEAP model include; Kadian et al. [24] for the household sector, Dhakal [10] and Pradhan et al. [36] for the transport sector in India and Nepal respectively.

Several studies in literature have focused on mitigation of GHG emission by shifting the energy utilization in demand side, while maximizing the potentials of diversification of the energy supply mix. This study falls into category where it intends to lessen GHG emissions by imposing policies in both supply and demand side for Nigeria energy system in a bottom-up approach manner through the use of the LEAP model. However, the only bottom-up study that comprehensively investigated the impact of energy policies in the Nigerian household was carried out by Ibitoye [23]. Thus, no other study has applied a bottom-up approach to ascertain the impact of energy policies in the future energy system in Nigeria and this study intends to fill the gap in the literature.

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. The values are imputed into the LEAP model based on the required data which may be available to the user. These are presented in the following sections.

2.2.1. Energy consumption

The total final energy consumption is calculated as follows [20]:

$$EC_n = \sum_i \sum_j AL_{n,j,i} \times EI_{n,j,i} \tag{1}$$

where EC is the aggregate energy consumption of a given sector, AL is the activity level and is a measure of the social or economic activity for which energy is consumed. AL is measured for each year as scale of