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Assessing the Macroeconomic Impacts of Financing Options for Renewable-Energy Policy in Nigeria: Insights from a CGE Model

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PAGE
policy analysis on growth and employment

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Abstract

In 2015, Nigeria formulated its Renewable Energy and Energy Efficiency Policy (NREEEP) to promote the development of renewable-energy systems in line with the Paris Climate Agreement and Sustainable Development Goals. With that as inspiration, we examined the effectiveness and macroeconomic impacts of Nigeria's renewable-energy policy using a computable general equilibrium (CGE) model. We calibrated the PEP-1-1 CGE model on Nigeria's updated social accounting matrix (SAM) and ascertained the effects on key energy, economic, and environmental variables. We found that a production subsidy was effective in developing the renewable-electricity sector and encouraging the use of renewable electricity, regardless of how the subsidy was financed. The fiscal incentive for the renewable-electricity sector had positive impacts on such key macroeconomic and welfare variables as employment, real GDP, household income, and welfare if the subsidy was financed by government deficit. Macroeconomic impacts were unfavourable, however, if the subsidy was financed by adjustments in government expenditures.

Keywords: Renewable Energy; Energy Policy and the Macroeconomy; CGE models, Nigeria.

JEL: Q42; Q43; L94; C68

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Table of contents

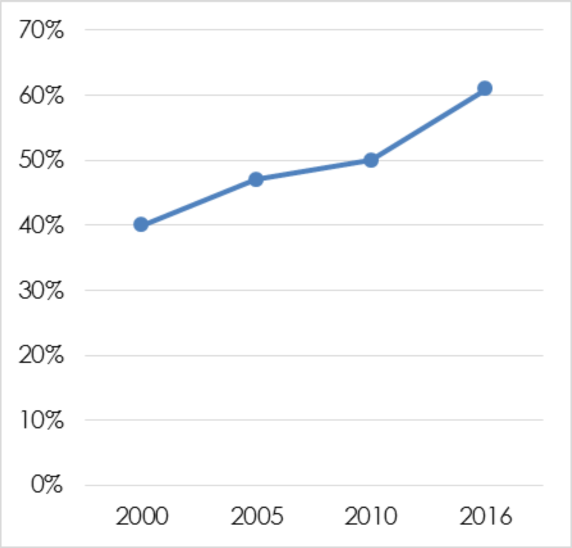
List of tables

List of figures

I. Introduction

Nigeria has one of the lowest rates of electricity access among energy-producing countries. According to the International Energy Agency's Energy Access Outlook Report (Organisation for Economic Cooperation and Development/International Energy Agency, 2017), electricity access in Nigeria has increased in recent years, but about 74 million Nigerians were still without electricity as of 2016 (Figure 1). There was also a large disparity between rural and urban electricity access (Figure 2). Due to unreliable electricity supply, most households and businesses in Nigeria generate own electricity through petrol and diesel generators. Based on the World Bank Enterprise Survey, about 58.8% of electricity came from generators (World Bank, 2015). Existing electricity generation capacity was mainly composed of fossil fuel (83%), while hydroelectricity accounted for 98% of renewable-energy source.[1] Expectedly, based on data from the database, energy-related CO2 emissions in Nigeria increased from 69.9 million metric tons in 1980 to 97.1 million metric tons in 2016, making Nigeria one of the top CO2 emitters in Africa.

Fig 1: Electricity Access Trends in Nigeria



Source: Organisation for Economic Cooperation and Development/International Energy Agency (2017).

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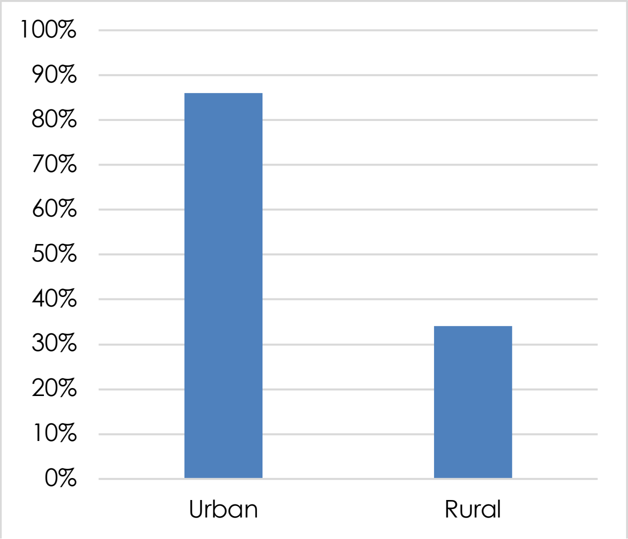
[1] Information taken from the United States Energy Information Administration (EIA) Online Statistical Database.

Fig 2: Urban and Rural Electricity Access in Nigeria, 2016



Source: Organisation for Economic Cooperation and Development/International Energy Agency (2017).

In order to ensure access to affordable, reliable, sustainable, and modern energy for all (United Nations Development Program Sustainable Development Goal 7), the Nigerian government formulated the National Renewable Energy and Energy Efficiency Policy (hereafter, NREEEP) in 2015. The policy's aims included reducing energy-related CO2 emissions, which is largely responsible for climate change (Stern, 2008; Intergovernmental Panel on Climate Change, 2011), and fulfilling the Nationally Determined Contributions in the Paris Climate Agreement. The NREEEP built upon the Nigerian Renewable Energy Masterplan produced in 2006 to promote the development of renewable energy in Nigeria and lays a clear framework for achieving renewable-energy targets (unlike the National Energy Policy of 2003).

The NREEEP set specific targets for different renewable-energy sources (see Table 1). In order to achieve those targets, the NREEEP also includes such measures and incentives as power-production tax incentives, tax holiday on dividend income from investments on domestic renewable-energy sources, excise-duty and sales-tax exemption, soft loans, grants or land allocations, and tax credits for users of energy-efficiency lighting and appliances, among others. According to Emodi and Ebele (2016), however, production-tax credits and structural tax policy were more practicable and administratively feasible fiscal incentives for the Nigerian renewable-electricity sector.

Table 1: Summary of Renewable Energy Targets under the NREEEP

Renewable energy type	2015 (Short term)	2020 (Medium term)	2030 (Long term)
Large Hydro	2121.00	4549.00	4626.96
Small Hydro	140.00	1607.22	8173.81
Solar	117.00	1343.17	6830.97
Biomass	55.00	631.41	3211.14
Wind	50.00	57.40	291.92
Total	2483.00	8188.20	23134.80
Share of renewable energy in total (projected) electricity generation	10%	18%	20%

Source: Ministry of Power (2015)

Note: Targets were based on the Model for Analysis of Energy Demand and Model for Energy Supply Strategy

Alternatives and their General Environmental Impact energy-planning models.

Although renewable-energy policies are aimed at addressing environmental problems, there are abundant research interests in their economic implications (International Renewable Energy Agency, 2016; Jenniches, 2018), with most studies applying CGE models (Bohringer et al., 2012; Dai et al., 2016). The literature on the economic impact of renewable-energy and environmental policies is extensive, but this is the first study, to the authors' knowledge, that examined the economic impacts of the NREEEP in particular. Moreover, it is also the first known study to account for self-generated electricity (from petrol and diesel generators), which is ignored in existing studies, especially for developing countries. It is in this context that this study investigates the effectiveness and macroeconomic impacts of the fiscal (production) incentives for Nigeria's renewable-energy policy using a CGE model. The specific research question is: what are the economy-wide impacts of production tax incentives for Nigeria's renewable-energy sector?

II. Literature review

Renewable energy has become an important part of the global energy mix, driven by the increasing threats of climate change and security concerns posed by over reliance on fossil fuels (International Renewable Energy Agency, 2017). However, the economic impacts of transitioning to renewable energy have also become an important research area (International Renewable Energy Agency, 2016) because of the crucial link between the structure of energy consumption and the economy (De Janosi & Grayson, 1972; Feng, Sun & Zhang, 2009). For instance, Li, Lu, and Zhang (2019) found that, while China's renewable-energy policies were beneficial for energy-structure adjustment and CO2-emission reduction, they had negative macroeconomic impacts.

Studies in this research area have used methods that have included reviews (Boluk, 2013), econometric analysis (Jaraitė et al., 2015; Silva. Soares & Pinho, 2012; McKitrick, 2013; Hillebrand et al., 2006), primary data analysis (Sastresa et al., 2010), macro-econometric modelling (International Renewable Energy Agency, 2016; Ragwitz et al., 2009), and meta-analysis (Nkolo, Motel & Djimeli, 2018) to CGE modelling (Bohringer et al., 2012; Bohringer, Keller & Van Der Werf, 2013; Dai et al, 2016).

While these studies have been diverse in focus and methodological approach, a main limitation of non-CGE studies has been that they have focused narrowly on a single economic indicator such as GDP and employment and have failed to capture economy-wide effects and sector changes that may have resulted from renewable-energy and environmental policy.

This limitation was explicitly addressed by Tavoni et al. (2015), who noted that emission-reduction expenditure costs were borne by emission-reducing sectors and would lead to a reduction in output and international competitiveness of those sectors via an increase in production costs. On the other hand, subsequent increases in the demand for emission-reduction goods would boost the output and competitiveness of the sectors producing them. Similarly, Bohringer et al. (2012) posited that renewable energy development was likely to have general equilibrium effects. Therefore, it was important to investigate the net effects of such policies.

CGE models have been widely used to investigate the macroeconomic effects of renewable-energy policies precisely because of their economy-wide effects. Most studies, however, have focused more on developed and industrialised countries with strong capabilities for renewable-energy innovation.

Huang (2010) used the CGE model developed by Lofgren et al. (2002) and modified by Holland, Stodick, and Painter (2007) to suit the Impact Analysis for Planning dataset to examine the effects of bioenergy policies in the Southeastern U.S. In the first stage, intermediate and primary inputs (land, capital and labour) were required in fixed proportions in the production of each unit of output. In the second stage, total intermediate input was specified by a Leontief function of disaggregated intermediate inputs while the primary inputs constant elasticity of substitution (CES) function was used to capture value-added. General investment, three household income classes, the federal and state government, and the rest of world are the major institutions in the model.

The study disaggregated bioenergy-production sectors directly from the Social Accounting Matrix (hereafter, SAM). The policy scenarios involved displacement of 1% conventional electricity generation with forest-biomass-based electricity, displacement of 1% of conventional liquid fuel with cellulosic ethanol, a $1.01 per-gallon subsidy for the production of cellulosic ethanol, and a 10% reduction in intermediate inputs for forest bioenergy sectors owing to technological advancement. The study found reductions in gross regional product and social welfare when conventional energy was replaced with forest biomass. On the contrary, the study found that enhancing technologies and providing incentives for forest bioenergy led to an increase in total labour demand, gross regional product, and welfare.

Focusing on Canada, Bohringer et al. (2012) employed a multi-sector and multi-region CGE model to evaluate the employment impacts of Ontario’s feed-in-tariff program. In the model, the CES for renewable-energy sector was a nested CES of capital, labour, energy, and material combined with a fixed-factor input to reflect limited renewable-energy sites. They also created a domestic manufacturing sector that produced renewable-energy equipment (turbine blades, solar panels, inverters, batteries, and so on) for the renewable-generation sector to reflect the minimum domestic content in the program. The study concluded that there was an overall net employment loss because positive effects on jobs in the renewable-energy and manufacturing sectors were offset by job losses in other sectors of the economy.

In a related study, Bohringer, Keller, and Van Der Werf (2013) analyzed the impact of renewable-energy promotion on employment and welfare in Germany using a CGE analysis. They simulated four alternative ways of financing the subsidy to power production from renewable energy sources: an electricity tax, a labour tax, a lump-sum tax, and a German coal-subsidies replacement. In all four financing scenarios, they studied the impact of various subsidized electricity-production rates from domestic renewable-energy sources (bar hydropower) on real consumption, real wage, electricity price, and unemployment. The subsidy was expressed as a percentage of consumer electricity price and varied from 0 to 100%, approximately reflecting the variety of technology-specific feed-in tariffs paid in Germany to various renewable technologies. They found that any positive effects on employment and welfare were limited and depended upon the level of subsidy rates and financing mechanisms. There were negative welfare and employment impacts if renewable energy subsidies were financed by labour taxes. On the other hand, they found a minor positive effect if an electricity tax was imposed to finance renewable energy, but these positive effects became negative after the subsidy rates exceeded threshold values. Studies on the Netherlands and the European Union also found positive effects of renewable-energy transition on GDP and jobs (Bulavskaya & Reynes, 2017; Fragkos & Paroussos, 2018).

Among developing countries, the majority of the literature has focused on China. Dai et al. (2016) examined the impact of large-scale renewable energy development in China using a dynamic CGE model. The study adjusted the standard CGE model in three different ways. First, the authors disaggregated the electricity production sector in the original input-output table into different categories (coal, oil, gas, nuclear, hydro, wind, solar PV, and biomass). Second, in the production function, all the sectors (except electricity) combined only labour and capital. The electricity sector was disaggregated into fossil and non-fossil electricity generation. Non-fossil electricity generation did not use fossil fuel, but was composed solely of labour and capital. On the other hand, fossil-fuel generation technology requires capital, labour, and energy, but energy was linked directly to output and not bundled with capital. This depicted a linear relationship between energy and output. Thirdly, the model also distinguished two types of investment—conventional investment and investment in construction of non-fossil fuel plants. The model considered two scenarios—a reference scenario and an aggressive renewable-energy-penetration scenario. Under the reference scenario, the non-fossil fuel and renewable-energy sectors experienced increased value-added and job creation while fossil-fuel and energy-intensive sectors experienced negative growth and job losses. There was a negative economic impact under the drastic-growth scenarios in which GDP and household consumption fell by 0.3-1.5%. The study suffered from limitations, however. It failed to incorporate foreign trade of renewable-energy technologies. This was particularly important given that China has the largest market and is a global player in the renewable-energy-technology market.

Mu et al. (2018) analyzed the employment impacts of China's renewable-energy policies using a CGE model. They decomposed these into direct, indirect, and induced impacts and used the static version of the China Hybrid Energy and Economic Research (CHEER) model. Capital was modelled on the production factor in the CHEER model to be completely mobile across sectors. Capital supply was calibrated to the base year, while capital demand differed endogenously in order to clear the capital market. They developed a reference scenario and two scenarios for renewable-electricity policy. The reference scenario was calibrated to 2012 as a baseline for the analysis without any further policy shocks. In the reference scenario, 103.0 TW h and 0.36 TW h, respectively, were generated from wind and solar sources. Subsequently, policy simulations were carried out to expand wind and solar power generation through feed-in tariffs (FITs) funded by (i) an additional electricity consumption fee and (ii) a lump-sum tax. Solar PV and wind expansions were each modeled independently. They found that solar PV and wind-power expansion per 1 TWh would generate about 45.1 thousand and 15.8 thousand direct and indirect jobs in China.

In addition to studies that have looked at aggregate renewable-energy policy, others have narrowed their scope to specific renewable-energy sources. Wianwiwat and Asafu-Adjaye (2013) examined the impacts of biofuel policy in Thailand using a CGE model composed of fifty-one sectors and sixty-two commodities. They disaggregated the energy-source industry into twenty-four energy sectors and thirty-two energy source goods, and they developed three new industries—Molasses-Ethanol (split from sugar refining), Cassava-Ethanol (split from tapioca refining), and biodiesel (split from palm oil)—to evaluate the effects of encouraging bio-liquid fuels. Four mixed-bio-liquid fuel industries (Gasohol-91, Gasohol-95, B3, and B5) were also disaggregated and treated as petroleum-refinery dummy industries. The disaggregation promoted the imposition of such policy shocks in capital stocks as an increase in the biodiesel sectors, cassava-ethanol, and molasses-ethanol. Furthermore, the model simulated different scenarios, including adding more bio-liquid fuels to mixed-bio-liquid fuels, for instance, raising the biodiesel content in B3 from 3% to 5% (B3 to B5). In addition, they disaggregated the electricity industry into four new sectors (hydropower, main electricity, small power producers, and very small power producers) to assess the impact of purchasing electricity from biomass-fired energy plants according to various technologies. The study analyzed these policy shocks: a 100% decrease in the use of gasoline-91 in all sectors except petroleum-refinery sectors, a 100% increase in ethanol content in E10 goods (E10 to E20), a two-thirds rise in biodiesel content in B3 (B3 to B5), and a 200% rise in biodiesel content in B5 (B5 to B20). They found that promoting biofuel led to rapid increases in biofuel prices and feedstock in the short run, but a slight increase in the long run.

Timilsina, Chisari, and Romero (2013) also focused on the economy-wide effects of biofuels in Argentina using a CGE model. In the model, intermediate consumption was disaggregated into diesel, biodiesel, gasoline, and ethanol. The scenarios included international prices changes of feedstocks and biofuels to promote exports and fiscal and regulatory-policy shocks designed to encourage domestic consumption of biofuels. The study found that increases in global feedstocks and biofuels prices would boost social welfare and GDP. On the other hand, domestic mandates for biofuels would result in minor losses in social welfare and economic output because a portion of feedstock and biodiesel was diverted from exports to reduced domestic consumption returns. In addition, an export-tax increase on either biodiesel or feedstock would result in a decrease in social welfare and GDP, though government revenue would increase.

Ge and Lei (2017) investigated the policy options for non-grain bioethanol in China using an economy-energy-environment CGE model in which output was decomposed into value-added and intermediate consumption. A CES function was further used to disaggregate value-added into labour and energy-capital composite, and the latter further into capital and energy. The energy input was further disaggregated into electricity and non-electricity using a CES, with the latter further decomposed into coal and non-coal. The study categorized the policy incentives into five scenarios and compared the effects on the macroeconomy, energy consumption, and CO2 emissions. The scenarios included a subsidy on bioethanol production, subsidies for the planting of non-grain feedstocks, subsidies on marginal-land reclamation, subsidies for more cities to consume bioethanol, and a consumption tax on gasoline. The study found that bioethanol-production and consumption subsidies could boost GDP while simultaneously reducing crude oil and gasoline consumption and CO2 emissions. This would, however, also result in an increase in coal and electricity consumption. On the other hand, a bioethanol-production subsidy could promote GDP and reduce energy consumption and CO2 emissions, but have limited effects on bioethanol development.

The International Renewable Energy Agency (2016) showed that major oil and gas exporting countries such as Saudi Arabia, Russia, Nigeria, and Venezuela would face a decline in GDP as a result of renewable-energy transition. As a result, new studies have emerged regarding oil-and-gas-export-dependent economies. Tabatabaei et al. (2017) used a static hybrid CGE model to examine the economic, energy, and environmental effects of feed-in-tariff (hereafter, FIT) policy on Iran's economy. They assessed the FIT policy under various scenarios in order to obtain the optimal conditions at which 10% of electricity could be produced from renewable sources. The results showed a decline in GDP by sector except in the electricity sector. Their work also revealed that a technology-neutral policy had fewer financial implications for government than a technology-specific policy and caused less reduction in GDP. They concluded that the application of subsidies to renewable energy, and the way they were financed, could affect the results of the FIT policy.

Though studies exist on the economic impacts of renewable-energy expansion or climate policy in Nigeria, those adopting a CGE model or macroeconomic modelling have remained very rare (Dayo et al., 2004). Ajayi and Ajayi (2013) examined energy policies and the legal ethics of renewable energy development in Nigeria. They focused on the country's legal framework of renewable-energy development by evaluating the nation's vision 20:2020 and the renewable energy master plan jointly developed by the United Nations Development Programs and the Energy Commission of Nigeria. Similarly, Lin and Ankrah (2019) adopted a ridge-regression technique to assess the economic impact of renewable energy in Nigeria and to examine the substitution and output elasticity of both renewable and non-renewable energy sources. Using a dataset from 1980 to 2015 within the framework of the translog production function model, the results showed that neither energy source exerted a significant impact on economic output.

Okoro, Schickhoff, and Schneider (2018) used a novel Forest and Agricultural Sector Optimization Model to assess the environmental and societal impacts of bioenergy policies under diverse global climate and societal development scenarios. Their findings showed that bioenergy subsidy had an insignificant impact on social welfare in Nigeria. Nigeria was also one of the reference countries in the International Renewable Energy Agency's report, Renewable Energy Benefits: Measuring the Economics (2016). The study found that the deployment of renewable energy had a negative effect on the GDP of Nigeria as a result of reduction in the export of fossil fuel. The deployment of renewable energy, however, led to an increase in welfare of 0.5-1.1%, depending on the scenario, coupled with $50 billion in fossil-fuel-import reductions. This study estimated the welfare impact through changes in the GDP, despite the limitations of GDP as a measure of economic well-being (Dynan & Sheiner, 2018). In contrast, in addition to estimating the impact of renewable-energy policy on GDP, employment, trade, fiscal position, and other macroeconomic indicators, our study measured welfare changes from the effects on household income and consumption.

Some gaps remain in the literature. First, studies on the aggregate macroeconomic impacts of environmental and renewable-energy policies in developing countries in general, and Nigeria in particular are very rare. Most empirical studies in the literature have focused considerably on developed countries such as Organisation for Economic Cooperation and Development and European Union countries, and their conclusions may not correspond to Nigeria or other developing countries. Nigeria depends on fossil fuel production and export for foreign exchange, government revenue, and electricity generation; hence the macroeconomic and sector-linked impacts of renewable-energy policies differ significantly from non-fossil fuel producing and exporting countries.

Between the formulation of renewable-energy policies in Nigeria in 2003 and the current National Renewable Energy and Energy Efficiency Policy initiated in 2015, no study empirically investigated economy-wide impacts. Second, in the case of Nigeria, there is a high level of self-generated electricity from diesel and petrol. This accounts for a significant proportion of the electricity supply in Nigeria, though this has usually not been considered in previous studies. Our study modeled energy in a CGE framework following the work of Ge and Lei (2017) and of Wianwiwat and Asafu-Adjaye (2013).

III. Methodology and Data

3.1. Data: Social Accounting Matrix (SAM)

The CGE model is calibrated to a SAM. The SAM describes the interrelations among all economic agents, sectors, and factors of production. It shows the circular flow of inflow (income) and outflow (expenses) of economic agents (Breisinger, Thomas & Thurlow, 2009) and describes how factors of production were allocated to sectors and how sectoral outputs are distributed among economic agents.

The latest SAM for Nigeria was published in 2010, based on 2006 national accounts data. According to Nwafor, Diao, and Alpuerto (2010), the data for constructing the SAM were obtained from various publications of key government agencies such as the Central Bank of Nigeria, the National Bureau of Statistics, and the Ministry of Agriculture and Water Resources. The main modules of the SAM include activities/sectors, commodities, factors of production, transaction costs, agents (households, firms, government, and rest of the world), taxes, stock variation, savings, and investment. The rest of the world and some taxes cover the international trade aspect of Nigeria's economic activities.

Three production factors are reported in the SAM: land, labour, and capital. Households are subdivided based on six geopolitical zones and rural/urban divides. In all, there are twelve categories of households (South South rural, South South urban, Southeast rural, Southeast urban, Southwest rural, Southwest West urban, North Central rural, North Central urban, Northeast rural, Northeast urban, Northwest rural, and Northwest urban). For this study, however, the twelve household categories were merged into one. There are also four categories of taxes: direct/income tax paid by households and firms to the government, indirect/sales taxes paid on commodities, activity tax paid by firms to the government, and import tax.

The SAM contains a total of sixty-one economic activities/sectors and sixty-two commodities, covering such activities as rice, potatoes, beans, maize, beef, goat meat, poultry meat, transport, finance, health, and NGOs. However, we aggregated all the agriculture-related activities and commodities into four major sectors/activities: crop production, fisheries, livestock, and forestry. Other sectors/activities remained as they were in the original matrix except for “beverages and tobacco products” and “processed foods,” which were merged and “transportation and other equipment,” which was absorbed into ”other manufactured product.” After adjusting the original SAM, twenty-five (25) sectors/activities and twenty-six (26) commodities remain.

The Nigerian economy has changed significantly in size and structure between 2006—whose national accounts data were used to build the SAM—and now, and the SAM may not reflect the current state of the economy. Given the absence of a recent input-output table to build a new SAM, this study followed the SAMBAL implementation in GAMS developed by Lemelin, Fofana, and Cockburn (2013) to update the SAM. Implementing the SAMBAL in GAMS, the Nigerian 2006 SAM was updated to national accounts data from 2013, a date that was selected because it was the latest year before the global oil price plunge adversely affected the Nigerian economy and produced a recession. The updated (2013) SAM provided the baseline data for this study.

Because renewable-electricity policy was the main focus of this study, the “utility” sector/activity and commodity in the updated SAM was disaggregated into water and electricity sectors and commodities, based on their proportions in national account data published by the Central Bank of Nigeria (2017). The electricity sector was further disaggregated to determine the respective shares of conventional fossil-fuel (FELE) and renewable-electricity (RELE) sectors and commodities based on Nigerian electricity-generation data obtained from the online database of the United States Energy Information Administration. A new self-generation electricity factor (SELE) was also created to capture the electricity produced from petroleum and diesel generators. We assumed that half of intermediate consumption of refined oil was used for self-generation of electricity. After all the modifications, the updated and revised SAM contained twenty-six sectors/activities and twenty-seven commodities.

3.2. Description of the Nigerian Economy Based on the Updated 2013 SAM

The SAM shows that the output of most sectors was largely made up of value-added (Table 2). On average, value-added accounted for 73.20% of total output. In terms of the factor intensity in each sector, all sectors of the economy, except other manufacturing, crude oil and gas, refined oil, other solid minerals, and construction, were labour-intensive. The most labour-intensive sectors included real estate, wholesale and retail trade, other services, hotel and restaurants, public service, education, and the banking and financial sector. Livestock, fishing, and forestry sectors also had high labour intensity. Land was used only in the crop-production sector and accounted for 42% of value-added while labour accounted for 58%. As anticipated, the proportion of labour in the value-added of the crude-oil-and-gas sector and refined-oil sector was very low at only 0.27% and 0.91%, respectively. These sectors were highly capital-intensive. The contribution of the electricity sector to value-added was low, reflecting the challenge of limited electricity supply in Nigeria vs. other production factors.

Table 2: Value-Added Coefficients, Intermediate Consumption, and Factor Intensity (%)

	Value-added coefficients and intermediate consumption			Sectoral factor intensity					
Sectors[2]	Value-added	Intermediate Consumption	Activity Tax	Labour	Capital	Land	SELE	FELE	RELE
CROP	91.41	8.60	-0.02	57.60	0.36	41.84	0.01	0.17	0.02
LIVE	61.27	38.21	0.51	72.02	27.29		0.69		
FISH	91.73	8.20	0.07	69.41	30.54		0.06		
FORE	78.53	20.71	0.76	71.68	25.96		0.14	1.97	0.26
BEVG	40.15	59.34	0.51	70.94	28.75		0.00	0.28	0.04
TEXT	56.55	42.97	0.48	62.35	37.40		0.07	0.15	0.02
WOOD	76.36	23.13	0.51	63.07	36.62		0.00	0.27	0.04
OMFC	57.43	43.69	-1.13	18.79	77.20		3.08	0.83	0.11
COIL	92.21	7.76	0.03	0.27	99.15		0.58		
ROIL	28.92	70.88	0.20	0.87	72.21		4.46	19.87	2.59
OMIN	81.41	18.59	0.00	7.22	83.97		2.16	5.88	0.77
CONS	80.83	18.72	0.45	2.11	97.47		0.21	0.19	0.02
WATER	81.11	18.30	0.59	54.71	40.98		3.41	0.79	0.10
FELECT	81.11	18.30	0.59	54.71	40.98		3.41	0.79	0.10
RELECT	81.11	18.30	0.59	54.71	40.98		3.41	0.79	0.10
RTRA	59.98	39.72	0.30	53.42	34.05		11.91	0.55	0.07
OTRA	49.43	48.00	2.57	54.85	26.01		16.85	2.02	0.26
TRAD	78.06	21.93	0.01	93.49	5.41		1.10		
HOTL	65.55	34.32	0.13	80.88	7.94		1.25	8.79	1.15
COMM	62.84	33.86	3.30	66.57	30.57		0.59	2.01	0.26
BSER	62.69	35.80	1.51	83.57	9.40		2.86	3.69	0.48
REST	88.71	10.89	0.39	98.16	1.55		0.30		
EDUC	61.09	38.91	0.00	82.68	0.12		2.71	12.81	1.67
HEAL	66.96	33.04	0.00	60.83	0.09		4.23	30.84	4.02
PSER	34.72	65.28	0.00	81.82	0.09		3.45	12.95	1.69
OSER	92.45	7.60	-0.05	92.96	0.59		0.87	4.94	0.64

Source: Authors' calculations from the updated 2013 SAM.

The SAM also shows export intensity by sector and import penetration by products in Table 3. Expectedly, the crude-oil sector accounted for the largest proportion of exports at 71.46%, followed by banking service and financial institutions at 11.60%. Other sectors with modest export intensity included the road-transport sector and other manufacturing. With respect to import penetration, other manufacturing accounted for 43.25% of imports, followed by road transport and refined oil at 11.64% and 11.08% respectively. The large import penetration of other manufacturing/transportation and other equipment corroborated the fact that local manufacturing of heavy equipment was almost non-existent and that

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[2] CROP=Crop production; LIVE=Livestock; FISH=Fisheries; FORE=Forestry; BEVG=Food and beverages; TEXT=Textile; WOOD=Wood and furniture products; OMFC=Other manufacturing; COIL=Crude oil and gas; ROIL=Refined oil; OMIN=Other minerals; CONS=Construction; WATER=Water; FELECT=Fossil electricity; RELECT=Renewable electricity; RTRA=Road transport; OTRA=Other transport; TRAD=Wholesale and retail trade; HOTL=Hotel and restaurant; COMM=Communications; BSER=Banking and other financial services; REST=Real estate; EDUC=Education; HEAL=Health; PSER=Public service; OSER=Other services

Nigeria depended upon the importation of these products. Other sectors with high import penetration included crop production and banking services and financial institutions.

Table 3: Export Intensity and Import Penetration (%)

Sectors	Sectoral export intensity	Import Penetration
CROP	1.45	10.91
LIVE		0.72
FISH	0.02	1.62
FORE	0.02	
BEVG	0.34	2.59
TEXT	0.85	1.15
WOOD	0.05	0.12
OMFC	5.02	43.25
FERT		2.43
COIL	71.46	0.18
ROIL		11.08
OMIN	1.19	2.26
RTRA	6.72	11.64
OTRA	1.29	2.17
BSER	11.60	9.90

Source: Authors' calculations from the updated 2013 SAM.

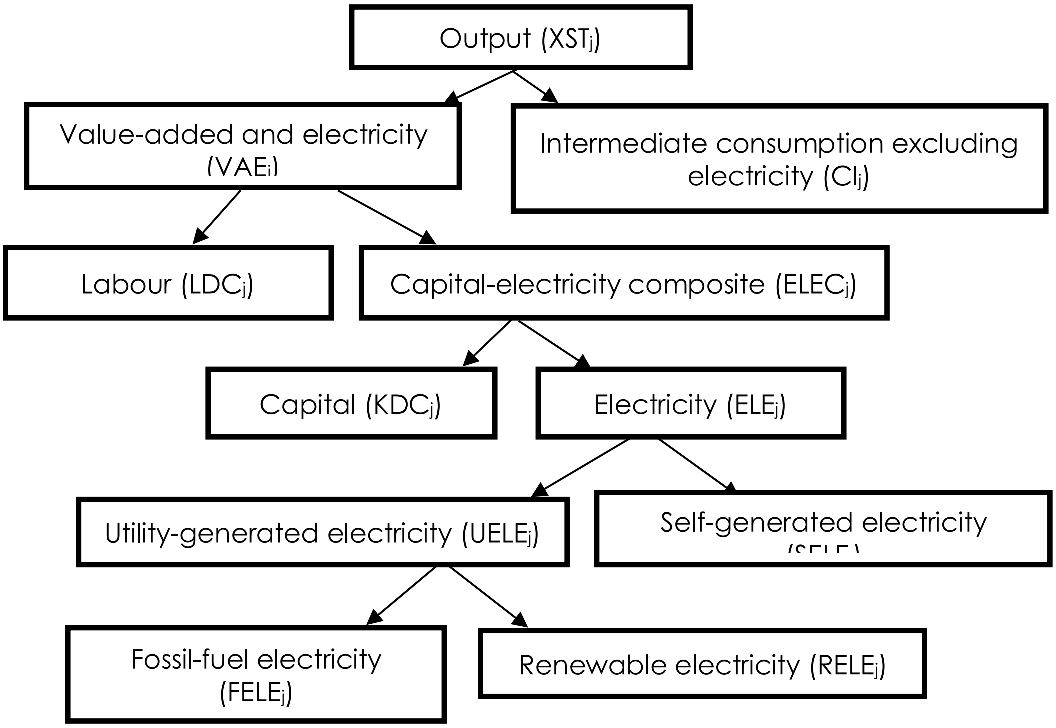
3.3. The Methodology: Extended PEP-1-1 CGE Model

Because of its suitability to assess the macroeconomic, distributional, and welfare impacts of public policies, CGE modelling has been widely used to evaluate the macroeconomic impacts of renewable-energy policy (Kretschmer & Peterson, 2010). It has been applied to analysis of energy and other economic policies in Nigeria (Iwayemi & Adenikinju, 2001; Adenikinju et al., 2009). For this study, the standard PEP 1-1 model developed by Decaluwé et al. (2013) was used as the reference CGE model. The PEP 1-1 model is a single-country static model. In the model, output is composed of intermediate consumption and value added in fixed proportion. Production is either used in the domestic market or exported, and this relationship is depicted by a constant elasticity of transformation (CET) function. Similarly, consumption comprises of both imported and domestically produced commodities, which are assumed to be imperfect substitutes (Sisso, Sawadogo & Natama, 2016). This was introduced using the Armington assumption with a CES function between imported and domestic commodities (Armington, 1969).

In the standard PEP-1-1 model, only labour and capital are recognised as main factors of production, and only these factors constitute value-added. According to Lin and Atsagli

(2017) in their study of factor substitution in Nigeria, however, there is evidence of substitutability between electricity and capital and electricity and labour in Nigeria. Similarly, other studies on renewable-energy policy have incorporated energy as a factor of production (Ge & Lei, 2017; Wianwiwat & Asafu-Adjaye, 2013). Therefore, based on the conclusions of Lin and Atsagli (2017), the CGE models of Ge and Lei (2017), Wianwiwat and Asafu-Adjaye (2013) and Van der Mensbrugghe (2017), we extended the PEP-1-1 model to incorporate electricity as a factor of production, as shown in Figure 3 below.

Fig. 3: Schematic Representation of Extended PEP-1-1 Model



Source: Ge and Lei (2017) and authors' calculations.

As shown in Fig. 2, a Leontief function was used to decompose the output of each sector into intermediate consumption (excluding electricity), and value-added and electricity. A constant elasticity of substitution (CES) function was then used to disaggregate the value-added and electricity composite into labour and capital-electricity composite (see Equation 1 in the appendix). Similarly, a CES function was employed to decompose the electricity-capital composite into electricity and capital (Equation 2). Furthermore, total electricity was made up of utility-generated electricity and self-generated electricity (Equation 3). Electricity supply from the utility could be from a fossil-fuel electricity producer or a renewable electricity producer, and this was modelled through a CES function (Equation 4). This was consistent with the goal of climate-change mitigation which requires the substitution of fossil-fuel energy sources with clean and renewable energy sources (Lin & Omoju, 2017). Lastly, a CES was used to disaggregate the choice of electricity used by households. We could not obtain the elasticity parameters for the CES functions specifically for Nigeria and therefore adopted the elasticities from Decaluwé, Martens, and Savard (2001).

The electricity-related elasticities—sigma_ELEC (0.6), sigma_ELE (0.9), and sigma_UELE (2)—were adapted from the work of Chi et al. (2014) for China and based on the authors' judgement. We also conducted a sensitivity analysis by varying the electricity elasticities to determine whether the results were sensitive to the choice of elasticity.

The study also included a CO_2 emission module to examine the environmental impact of the policy. Emissions were those related to the use of electricity by sectors and economic agents. Fossil-fuel electricity, renewable electricity, and self-generated electricity in Nigeria mainly use natural gas, hydro, and oil respectively, and the corresponding emission coefficients were obtained from Moomaw et al. (2011).

IV. Results

Our study simulated the effects on the macroeconomy of key policy incentives for Nigeria's renewable-energy policy. Though the NREEEP document did not stipulate a specific production-tax rebate, we adopted a 20% production subsidy for the renewable-energy sector. We created two scenarios (as shown in Table 4) to describe the government's policy actions. The first scenario assumed that real government expenditure was exogenous and that the shortfall in government revenue occasioned by the subsidy would be borne by deficit/borrowing. The second scenario assumed that government could adjust its expenditures but keep deficit/savings unchanged. We determined how this closure rule influenced the impact of a production subsidy for the renewable-electricity sector.

Table 4: Financing/Fiscal Incentive Scenarios for Renewable Energy

Scenario A	20% production subsidy for the renewable electricity sector (Real Government Expenditure—G_REAL—is exogenous)
Scenario B	20% production subsidy for the renewable electricity sector (Government Savings—SG—is exogenous)

Source: Authors' calculations.

4.1 Overview of Macroeconomic Impacts

A summary of the impact of a 20% production subsidy for the renewable-electricity sector on key macroeconomic indicators is presented in table 5 below. As seen in the table, government revenue from production tax decreased by 33.94% as an immediate impact of the production subsidy. However, the negative impact on total government revenue/income was modest (0.71%) because of the mitigating effects of government income from other sources. Government income from household taxes, business income taxes, indirect taxes on commodities, import taxes, capital income, and transfer income increased by 0.82%, 0.11%, 1.70%, 2.35%, 0.11%, and 0.37% respectively, largely compensating for income loss from the production subsidy. Government expenditure on goods and services increased by 0.39%. Public consumption of education and health increased by 0.13% and 0.78%, respectively, while that of public administration dropped by 0.01%. The changes in government finances led to a net reduction of 1.35% in government savings, implying that government deficit increased by 1.35% as a result of the production subsidy. Although household and firm savings increased, real gross fixed-capital formation and total investment expenditure dropped by 0.60% and 0.42% respectively, as a result of the reduction in government savings which overrode the increase in household and firm savings (crowding-out effect).

While nominal GDP (at market price) increased by 0.50% as a result of the production subsidy, real GDP only increased by 0.13% as a result of the effect of price changes because the consumer price index increased by 0.37% (Table 5). This, to some extent, invalidated the hypothesis that renewable energy and environmental policy were not pro-growth (Jacobs, 2012). As we expected, an increase in economic output led to reduction in unemployment rates by 2.81% (Table 5) in alignment with the average demand for labour, which increased by 1.29% (Table 7).

On the other hand, if the production subsidy for the renewable-electricity sector were financed through a reduction in government spending, the impacts appeared worse for most macroeconomic indicators. The reduction in government income from production tax was 42.78% compared to 33.94% under the first scenario. As predicted, government total income and expenditures also fell by a higher proportion than they did under the scenario in which the subsidy was financed by government deficit. The decline in economic output in most sectors led to a fall in GDP (real GDP declined by 0.61%,) with a negative impact on employment. Underemployment increased by 10.31% under this scenario. The decline in savings, driven by the drop in household and business savings, led to a significant decline in total investment expenditure and gross fixed-capital formation by 8.73% and 3.17%.

Table 5: Summary of Impacts on Macroeconomic Indicators

INDICATORS/VARIABLES	CODE	SCENARIO A	SCENARIO B
Government revenue from production tax	TIPT	-33.94	-42.78
Total government income	YG	-0.71	-5.65
Government expenditure on goods and services	G	0.39	-16.9
Government savings	SG	-1.35	-
Unemployment rate	UR	-2.81	10.31
Wage rate	W	0.66	-7.47
GDP at market prices	GDP_MP	0.50	-7.13
Real GDP at market prices	GDP_MP_REAL	0.13	-0.61
Real gross fixed-capital formation	GFCF_REAL	-0.60	-3.17
Total investment expenditures	IT	-0.42	-8.73
Consumer price index	PIXCON	0.37	-6.56
Total CO_2 emissions	EMISSIONTOT	-4.12	-7.36

Source: Authors' calculations.

The incentive also led to changes in sector-based output. As expected, the output of the renewable-electricity sector increased by 23.61% while that of fossil-fuel electricity declined by 5.45% (Table 6). The impact on the output of the other sectors was mixed. These effects were driven mainly by changes in value-added. The rise in the renewable-electricity vs. fossil-fuel-electricity output confirmed the effectiveness of the production subsidy in the development of the renewable-electricity sector. In the scenario in which government expenditure was reduced to accommodate the production subsidy, the increase in the output of the renewable-electricity sector was lower while fossil-fuel-electricity output declined by a higher margin. The impact on the output of other sectors was mixed.

Table 6: Impacts on Output by Sector

Sector	Scenario A	Scenario B
crop	0.72	1.40
live	0.73	-0.71
fish	0.79	-0.25
fore	0.82	-1.76
bevg	1.08	0.66
text	1.17	0.07
wood	0.13	-0.41
omfc	-0.17	2.80
coil	0.00	0.04
roil	-0.49	-1.05
omin	0.00	1.57
cons	-0.03	-0.08
water	1.27	-4.21
felect	-5.45	-7.58
relect	26.31	23.45
rtra	-0.36	7.38
otra	0.01	7.29
trad	-0.03	-1.64
hotl	0.85	-3.02
comm	0.66	-3.43
bser	-0.28	7.62
rest	0.98	-2.73
educ	0.46	-2.92
heal	-0.49	-3.51
pser	-0.01	-10.43
oser	0.79	-2.59

Source: Authors' calculations.

4.2 Demand for Production Factors

Fiscal incentives for the development of renewable energy had an impact on the demand for production factors (Table 7). Providing a production subsidy for the renewable-energy sector led to a reduction in the relative price of the renewable-energy commodity by 11.97%. The price of self-generated and fossil-fuel electricity also declined by 0.80% and 1.92%, respectively. The large reduction in the price of renewable electricity was attributable to the production subsidy, which reduced the unit production cost of the renewable-energy commodity compared to other electricity sources. As a result of lower price, the use of renewable electricity increased in most sectors. The use of fossil-fuel and self-generated electricity also increased marginally in some sectors, however, implying that a production subsidy for the renewable-electricity sector did not exert significant substitution of fossil fuel for renewable energy in all economic sectors. Though the production-subsidy incentive significantly increased the use of renewable electricity across sectors, it did not lead to an overall decrease in fossil-fuel- and self-generated electricity under either scenario. A more significant reduction in the demand for self-generated electricity appeared to occur in Scenario B, however.

Labour demand also responded to the price change in electricity. The significant reduction in the price of renewable electricity led to a mixed effect on the demand for labour across sectors. The demand for labour fell in some sectors, but this effect was overridden by the substantial increase in the demand for labour in the renewable-energy sector. Overall, there was a net increase in the demand for labour, which induced an upward effect on the wage rate of 0.66%. In Scenario B, the impact on the demand for labour was mixed, but the demand for labour declined more in labour-intensive sectors, leading unemployment to increase by 10.31% and wages to decrease by 7.47%.

Table 7: Demand for Production Factors (% Change)

	Scenario A				Scenario B			
Sectors	LD	FELE	SELE	RELE	LD	FELE	SELE	RELE
crop	1.25	0.26	0.68	24.47	2.43	0.96	-4.08	25.31
live	1.01		1.31		-0.95		-3.05	
fish	1.14		1.34		-0.35		-2.77	
fore	1.05	0.33	0.74	24.54	-2.49	-0.91	-5.86	22.98
bevg	1.52	0.35		24.57	0.92	0.26		24.44
text	1.88	0.70	1.12	25.01	0.11	0.70	-4.33	24.98
wood	0.20	-0.18		23.91	-0.66	-0.37		23.65
omfc	-1.05	-0.11	0.31	24.00	14.56	7.70	2.32	33.67
coil	-1.03		0.46		12.48		2.07	
roil	-8.12	-3.72	-3.32	19.52	-10.82	-4.73	-9.49	18.23
omin	-1.70	-0.70	-0.28	23.27	14.02	6.34	1.03	31.98
cons	-1.80	-0.63	-0.22	23.35	-3.26	-0.17	-5.16	23.90
water	2.16	1.29	1.71	25.74	-7.23	-1.35	-6.28	22.43
felect	-9.59	-3.82	-3.42	19.39	-13.00	-4.01	-8.80	19.13
relect	49.49	18.98	19.47	47.70	44.09	18.87	12.94	47.53
rtra	-0.84	0.20	0.62	24.39	13.33	8.14	2.75	34.22
otra	-0.40	0.51	0.93	24.78	12.26	7.95	2.56	33.97
trad	-0.04		0.96		-1.71		-3.67	
hotl	0.55	1.32	1.74	25.78	-3.80	-1.18	-6.11	22.65
comm	0.89	0.36	0.78	24.59	-5.09	-1.70	-6.61	22.00
bser	-0.51	0.35	0.77	24.57	8.71	5.70	0.42	31.19
rest	0.99		1.42		-2.77		-4.11	
educ	-0.45	2.54	2.97	27.29	-3.62	-0.89	-5.84	23.01
heal	-2.60	0.43	0.85	24.68	-5.33	-2.39	-7.26	21.15
pser	-0.94	2.00	2.43	26.63	-11.06	-8.63	-13.20	13.40
oser	0.48	2.91	3.34	27.75	-2.88	-0.17	-5.16	23.89

Source: Authors' calculations.

4.3 Impacts on Household Income, Consumption, and Welfare

The transition to renewable energy through a production subsidy had an impact on household income and welfare. The increase in the wage rate of 0.66% led to an increase in household labour income of 0.97% (Table 8). Household capital and transfer income also increased by 1.51% and 0.25%, respectively. As a result, total household income increased by 0.82%. Following the increase in household income, household consumption of goods and services increased for most commodities, except for refined oil, fossil-fuel electricity, and health (Table 9). In line with the objective of the NREEEP, household consumption of renewable electricity increased by 26.77% while the consumption of fossil-fuel electricity and refined oil fell by 8.34% and 11.42%, respectively. In all, taking into consideration the effects of price changes, the household consumption budget increased by 0.44%, implying positive household welfare effects.

Conversely, all household indicators showed negative impacts under Scenario B. Given the decrease in the wage rate (7.47%), household labour income declined (by 8.53%). Similarly, income from capital and government transfer also declined by 5.96% and 5.32%, respectively, the latter as a result of a decline in government income (5.65%) and expenditures (16.9%). This led to a reduction in household savings and in the consumption budget (welfare). By implication, if the government were to reduce expenditures to accommodate the production subsidy for the renewable-electricity sector, the effects on household welfare indicators would be negative.

Table 8: Household Income, Consumption Budget, and Savings (% Change)

Variables	Code	Scenario A	Scenario B
Household capital income	YHK	1.50	-5.96
Household labour income	YHL	0.97	-8.53
Household transfer income	YHTR	0.25	-5.32
Total household income	YH	0.82	-7.42
Real household consumption budget	CTH_REAL	0.44	-0.92
Household savings	SH	0.82	-7.42

Source: Authors' calculations.

Table 9: Household Consumption of Commodities

Commodities	Scenario A	Scenario B
crop	0.96	-0.16
live	0.84	-1.27
fish	0.89	-1.09
fore	0.85	-1.99
bevg	1.39	-0.20
text	1.68	-1.32
wood	1.19	-2.27
omfc	0.25	8.20
roil	-11.42	-27.82
water	1.78	-4.68
felect	-8.34	-10.18
relect	26.77	24.19
rtra	0.19	7.85
otra	0.39	5.04
trad	1.03	-1.80
hotl	0.92	-2.57
comm	1.27	-3.56
bser	0.77	0.93
rest	1.08	-2.52
educ	0.47	-2.60
heal	-0.56	-3.18
oser	0.79	-2.60

Source: Authors' calculations.

4.4 Impact on Foreign Trade

Though the NREEEP aimed to develop the renewable-energy sector and induce the use of renewable vs. fossil-fuel electricity, it also had an impact on foreign trade via its effects on the price of domestic commodities. For most commodities, the increase in domestic price (PD) was higher than the increase in the price of exports (PE) (see Table 10). This made domestic commodities pricier than commodities on the world market, indicating lack of competitiveness. As a result, exports of these commodities fell (see Table 11), with the exception of crude oil and other minerals (which increased by 0.03% and 0.36%, respectively, because the domestic price was more competitive than export prices; that is, the reduction in domestic price of these two commodities was higher than the price reduction of exports). Therefore, the production subsidy for the renewable-electricity sector influenced exports via the impact of domestic and export prices. In Scenario B, exports increased in all exporting sectors (Table 11) because the price of domestic commodities fell more than did the price of exports (Table 10). This made locally produced commodities more competitive on the world market. Thus, this scenario was more favourable to exports.

Table 10: Impact on Export, Import and Domestic Prices

Sector	Scenario A			Scenario B		
	PE	PD	PM	PE	PD	PM
crop	0.30	0.95	0.03	-3.74	-6.75	-0.31
fish	0.23	0.84	0.04	-3.68	-7.32	-0.48
fore	0.18	0.76		-3.53	-7.69	
bevg	0.16	0.87	0.02	-3.54	-6.73	-0.21
text	0.20	1.04	0.02	-3.54	-7.21	-0.29
wood	0.30	0.67	0.03	-3.63	-7.34	-0.34
omfc	0.11	0.15	0.02	-1.49	-1.78	-0.20
coil	-0.01	-0.26	0.01	-0.05	-0.68	-0.07
omin	-0.18	-0.42	0.00	-0.77	-0.77	0.00
rtra	0.20	0.27		-3.63	-4.04	
otra	0.12	0.30		-3.87	-4.45	
bser	0.32	0.65		-5.14	-7.86	
fert			0.17			-2.00
live		0.76	0.01		-7.31	-0.13
roil		-1.40	0.00		-5.63	0.00

Source: Authors' calculations.

Similarly, imports were influenced through relative changes in domestic and import prices (Table 9). The increase in import prices was relatively lower than the increase in domestic prices, making imports more competitive than domestic commodities, with the exception of refined oil, crude oil, and other minerals. In this case, domestic prices fell relative to import prices, which made imports more expensive. This impact is shown in Table 11. The import of crude and refined oil and other minerals declined by 0.99%, 3.26%, and 0.96%, respectively, while that of other commodities increase. The opposite was the case under Scenario B. Imports of all commodities except other minerals and fertiliser increased.

Table 11: Impacts on Imports and Exports

	Imports		Exports	
Commodities	Scenario A	Scenario B	Scenario A	Scenario B
crop	2.61	-11.36	-0.60	7.91
live	2.26	-14.47		
fish	2.41	-13.50	-0.46	7.79
bevg	2.85	-12.18	-0.32	7.48
text	3.37	-13.90	-0.40	7.48
wood	1.44	-13.98	-0.60	7.68
omfc	0.11	-0.45	-0.22	3.05
coil	-0.99	-2.22	0.03	0.11
roil	-3.26	-11.87		
omin	-0.96	0.03	0.36	1.56
rtra	0.28	-1.65	-0.40	7.68
otra	0.72	-2.40	-0.24	8.21
bser	1.30	-11.01	-0.64	11.12
fert	0.72	1.40		
fore			-0.36	7.46

Source: Authors' calculations.

4.5 Sensitivity Analysis

As noted in section 3.3, the elasticity used in the study was adopted from the studies of Decaluwé, Martens, and Savard (2001) and Chi et al. (2014). We conducted a sensitivity analysis by varying the electricity-related elasticities to determine whether the results were sensitive to the choice of elasticity. The electricity-related elasticities varied by ±0.2. Only the results of the core macroeconomic indicators are reported here for brevity purpose (Table 12). The results were very similar to what was obtained in the standard model (Table 5). This indicates that the choice of elasticity did not significantly alter the direction of the impacts but only their size.

Table 12: Sensitivity Analysis: Impacts on Macroeconomic Indicators

INDICATORS/VARIABLES	CODE	Scenario A1	Scenario A2	Scenario B1	Scenario B2
Government revenue from production tax	TIPT	-34.26	-33.60	-41.54	-44.89
Total government income	YG	-0.72	-0.69	-4.70	-7.13
Government expenditure on goods and services	G	0.39	0.40	-14.14	-21.32
Government savings	SG	-1.37	-1.32	-	-
Unemployment rate	UR	-2.84	-2.80	7.74	14.50
Wage rate	W	0.66	0.66	-5.96	-9.84
GDP at market prices	GDP_MP	0.52	0.51	-5.69	-9.37
Real GDP at market prices	GDP_MP_REAL	0.14	0.13	-0.47	-083
Real gross fixed-capital formation	GFCF_REAL	-0.61	-0.58	-2.48	-4.27
Total investment expenditures	IT	-0.44	-0.39	-6.92	-11.57
Consumer price index	PIXCON	0.37	0.38	-5.25	-8.61
Total CO_2 emissions	EMISSIONTOT	-4.04	-4.23	-6.74	-8.34

Source: Authors' calculations.

V. Conclusions and Policy Implications

This study used a CGE model to analyze the macroeconomic impacts of Nigeria's renewable-energy policy instruments. The policy was initiated as an action plan following the ratification of the Paris Climate Agreement and the Sustainable Development Goals. It aimed to promote the development of renewable energy to enhance energy access for sustainable development while minimising environmental damage. We examined the effectiveness and macroeconomic effects of fiscal incentives proposed to facilitate the development and promotion of Nigeria's renewable-energy sector. The research objective was investigated with an extended PEP-1-1 CGE model, which was used to calibrate the updated 2013 Nigerian SAM. A 20% production subsidy for the renewable-electricity sector was simulated under two scenarios—financed by deficit or financed by a reduction in government expenditure.

The main conclusion of the study is that a production subsidy for the renewable-energy sector led to a significant increase in the use of renewable electricity factor across all sectors, but had a minimal effect on reducing fossil-fuel and self-generated electricity. In other words, the use of renewable electricity increased across sectors, but fossil-fuel and self-generated-electricity use did not decline in all sectors, implying a limited substitution effect.

This was consistent under both scenarios. Household consumption of renewable electricity also increased while that of fossil fuel and refined oil declined. In all, the incentive resulted in an increase in the output of the renewable-electricity sector, suggesting that the subsidy was effective in enhancing the development of the sector in Nigeria.

As expected, the production subsidy led to a reduction in government income and, ultimately, in government savings. On the other hand, there was an increase in labour and overall household income because the induced labour demand from the development of the renewable-electricity sector exerted upward pressure on the wage rate. In line with the increase in income, the consumption budget of households increased, suggesting an improvement in welfare. The increase in the savings of households and firms was overridden by the decrease in government savings, which lead to decline in investment and gross fixed-capital formation. Real GDP increased while unemployment declined, suggesting that renewable energy and environmental policies were compatible with growth and job creation. The policy incentive influenced foreign trade through its effects on import and export prices in contrast to domestic prices. Lastly, the changes in electricity sources induced by the production subsidy for the renewable-electricity sector caused a decline in CO_2 emissions of 4.12%. Unlike the macroeconomic impacts described above, Scenario B had many negative macroeconomic impacts on government income and savings; on household income, consumption, and savings; and on gross fixed-capital formation and investment expenditure, unemployment, and real GDP. Nevertheless, it was more favourable to exports and higher emission-reduction effects.

The results of this study have implications for Nigeria’s renewable-energy policy and broadly for sustainable economic development. Government fiscal incentives for renewable energy—in specific, a production subsidy—were effective in promoting the development and use of renewable electricity regardless of how that subsidy was financed. Macroeconomic impacts, conversely, were substantially determined by how the subsidy was financed. Based on the results of the simulations, this study suggests that the production subsidy for the Nigerian renewable-electricity sector should be financed by fiscal deficit to ensure that the primary objective of developing renewable energy is achieved without undermining macroeconomic stability and welfare.

The study has some limitations. First, the disaggregation of the SAM into water and electricity and further into fossil-fuel electricity and renewable electricity was parallel. Data to disaggregate the SAM into these categories were not available for each sector; thus we used the same proportion across all sectors. Data on the proportion of different types of energy in different sectors would have enriched the analysis and made it more accurate. Second, this study only simulated the impact of fiscal incentives proposed for the NREEEP, though NREEEP policy included other non-fiscal instruments. Future studies could investigate the impact of these instruments and incentives to determine optimal policy options. Third, given that the policy set targets to be achieved over a long term, there is a need to ascertain the impacts of the policy over time, and further studies should be conducted on the policy using dynamic CGE models.

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Appendix

Unlike the standard PEP-1-1 model, the value-added equation in this study was expressed in Eq. 1, in which LDC was composite labour while ELEC was capital-electricity composite.

$$VAE_j = B_j^{VAE}[\beta_j^{VAE} LDC_j^{-\rho_j^{VAE}} + (1-\beta_j^{VAE})ELEC_j^{-\rho_j^{VAE}}]^{\frac{1}{\rho_j^{VAE}}} \dots\dots\dots\dots\dots\dots\dots.1$$

The capital-electricity composite was further disaggregated into capital (KDC) and composite electricity (ELE) using the CES function in Eq. 2.

$$ELEC_j = B_j^{ELEC}[\beta_j^{ELEC} KDC_j^{-\rho_j^{ELEC}} + (1-\beta_j^{ELEC})ELE_j^{-\rho_j^{ELEC}}]^{\frac{1}{\rho_j^{ELEC}}} \dots\dots\dots\dots.2$$

Electricity supply in Nigeria comes from the power utility or self-generation. According to the World Bank (2015), a significant proportion of electricity is generated from diesel and petrol generators by individual households and enterprises due to limited and unreliable supply by the power utilities. This is expressed in Eq. 3 below:

$$ELE_j = B_j^{ELE}[\beta_j^{ELE} UELE_j^{-\rho_j^{ELE}} + (1-\beta_j^{ELE})SELE_j^{-\rho_j^{ELE}}]^{\frac{1}{\rho_j^{ELE}}} \dots\dots\dots\dots\dots\dots\dots.3$$

Lastly, electricity from the power utility is from either fossil fuel or renewable-energy sources as shown in Eq. 4:

$$UELE_j = B_j^{UELE}[\beta_j^{UELE} FELE_j^{-\rho_j^{UELE}} + (1-\beta_j^{UELE})RELE_j^{-\rho_j^{UELE}}]^{\frac{1}{\rho_j^{UELE}}} \dots\dots...4$$

The equation depicting the CO2 emissions of each sector is shown in Eq. 5:

$$EMISSION_j = \sigma_{gas} * FELE_j + \sigma_{hydro} * RELE_j + \sigma_{oil} * SELE_j \dots\dots..\dots.\dots.5$$

where EMISSIONj denotes the CO2 emission of industry j, σ_{gas}, σ_{hydro}, and σ_{oil} were the lifecycle emission coefficients of each electricity source.

$$EMISSIONAGO_h = \sigma_{gas} * CO(FELE_h) + \sigma_{hydro} * CO(RELE_h) + \sigma_{oil} * [0.5 * CO(ROIL_h)]\dots5$$

where EMISSIOANGOh was total CO2 emission from household consumption of electricity; CO(FELEh), CO(RELEh), CO(ROILh) were the consumption of fossil-fuel electricity, renewable electricity, and refined oil for self-generated electricity by household.