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Original Article

Using Machine-Learning Application to model the Causal Relationship between Electricity Consumption and Economic Growth in Nigeria

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Abstract - *This study examines the correlation between electricity consumption and economic growth in Nigeria using time-series data between 1990 and 2020. The study uses a Recurrent Neural Network (RNN), a machine learning application, to model the relationship between electricity consumption and Gross Domestic Product (GDP), representing the independent and dependent variables, respectively. A 30-year time series data for both variables forms the input data used in training the model and examining the causal relationship between the two variables. The study's outcome compares the actual GDP plot against the predicted values. The predicted GDP values track the actual GDP values with a high degree of accuracy. The RNN establishes a strong correlation between electricity consumption and economic growth in the country and provides an option for making a forecast of future GDP growth trends that are linked to an electricity supply scenario. There is a significant supply-demand gap in the electricity market in Nigeria, which calls for substantial investments to be made to achieve infrastructure upgrades, network expansion and improvement in service quality in the industry.*

Keywords - *Correlation, Electricity, GDP, Macroeconomics, RNN.*

1. Introduction

A robust government policy that promotes energy production and consumption is a key enabler for economic growth in a country. Energy consumption and economic growth are often mutually linked. The availability of cheap and reliable primary energy sources and the processing of such energy sources to useful secondary energy options, such as electricity, helps in fuelling economic growth in a society. Nigeria is blessed with an abundance of primary energy sources, both in terms of fossil fuels such as coal, oil, and gas and in green energy options such as wind, solar and hydro.

However, Nigeria has grappled with significant electricity deficiency problems for decades, which is considered a major contributor to the country's sluggish economic development. This is due to a myriad of problems, ranging from capacity constraints, aging infrastructures, low investments in the electricity sector, burglary (theft), and vandalism of infrastructures. Other contributing factors include the government's legacy equity-holding in the industry, weak policy and governance, a poor roadmap on energy transition, and a challenging business environment.

The challenge with the availability and consumption of electricity in Nigeria sharply contrasts with energy consumption trends in most developing countries and regions. Electricity consumption has increased much faster in developing economies, especially in Central South America and Asia, than in the more developed economies in the West. In 2013, the total amount of energy used in Africa (710 TWh), Central and South America (1,050 TWh), and Asia (9,820 TWh) increased 2.3 times, 2.4 times, and 5.8 times, respectively, from the 1980 levels. However, electricity consumption grew by 1.48 times and 0.87 times in Europe and North America, respectively, during the same period, significantly less than in the emerging and developing nations [11]. The increase in the demand and consumption of energy across most countries is linked to the expansion of national economies and a shift in the global social systems. Energy deficiency arises when there is a challenge with increasing energy supply to meet growing demands. This often leads to a slowdown in economic growth, except in situations where a shortfall in supply is complemented by imports. The overall energy cost, both in terms of unit production cost and per capita consumption cost, and the method of purchase have reasonable impacts on some critical competitiveness parameters for most countries. Therefore, energy abundance and, conversely, energy deficiency have become very relevant and have risen to prominence as issues of global concern, together with the rising price of energy supplies required to meet increasing demand across nations. Another issue that is of global relevance is the fact that most primary natural energy resources, especially fossil fuel, are concentrated in a few nations that are in relatively unstable regions. Any instability in those economies could pose a threat to the reliability of the global energy supply. Energy supply plays a crucial role in the sustenance and running of commercial activities as well as in fostering long-term growth; therefore, the cost-effective acquisition of a sufficient quantity of high-quality energy resources on time is of paramount importance, and this is linked to well-being and the ability to attain sustainable growth. The other issue that is slightly different but somewhat closely related is the efficient use of available energy.

The annual electricity consumption in Nigeria as of 2016 was 24.72 billion kWh [9], a headline figure for the country's annual energy consumption. Based on the country's population and energy demand profile, this number is grossly inadequate and represents a significant shortfall compared to electricity demand. On average, this amounts to about 144 kWh per person per year, which ranks Nigeria as the country with one of the lowest per capita electricity consumptions in the world, even amongst the developing countries. As stated earlier, Nigeria has an enormous amount of primary energy sources, and the country can easily achieve self-sufficiency in meeting its energy needs if the primary energy sources are optimally processed. However, the total output from Nigeria's electricity generation plants is insufficient to meet local demand, including the supply to a few neighbouring countries which Nigeria has electricity supply agreements with, being part of the treaty put in place to safeguard the generation of electricity at the river Niger hydro-power plant (Kainji Dam). Unfortunately, the unreliable power supply situation in Nigeria has greatly impacted the country's economy, leading to low industrial output and an overall negative impact on the production of goods and services. This situation is a direct contributor to increased poverty levels. The option of standby generators, which has become a default solution in most places, is being used to provide supplementary power to homes, offices, and industries. In addition, Nigeria has not attained full nationwide electricity supply coverage across every section of the country, as some rural areas are not yet connected to the national grid.

Various researchers have made use of a wide variety of statistical measurement techniques to investigate time series data, looking for patterns in energy consumption in Nigeria and across other countries in connection with growth in their Gross Domestic Product (GDP). The outcome of these studies leads to the conclusion of the existence of a bi-directional relationship between the two. This has been the subject of various studies carried out by [14], [1], [2], and [17], which all examined the link between energy use and industrial development and concluded the existence of a causal relationship between the two variables. Various researchers have performed empirical studies of the relationship between energy consumption and GDP growth, checking for unidirectional and bidirectional correlation and using different modeling tools such as Ordinary Least Square (OLS), Granger causality, and Johansen co-integration, among others. Depending on the data series and the modeling technique used, comparing the various studies indicates similarities and some level of variance in their outcomes. The likely causes of the discrepancies include methodological differences, data selection biases, and data quality or model definition problems. It is worth noting that most of these works approached the correlation between electricity consumption and GDP growth through feedback techniques. However, given some of the discrepancies observed over the period, this study is focused on using the recurrent neural network technique and a feed-forward approach to examine the correlation between electricity consumption and economic growth in Nigeria.

The generation and consumption of electricity have significantly contributed to improving the quality of life in society. It is a vital component required for infrastructure development and industrialization efforts. From an electricity supply perspective, little consideration has been given to Nigeria's rapidly expanding population, resulting in the increasing energy demand trend. Nigeria's long-term development plans often appear to be devoid of strategic ideas required to address the large-scale energy deficiency situation in the country. In terms of electricity supply and infrastructure investment, greater priority is usually given to the urban areas and sometimes to the detriment of the rural and sub-urban dwellers. This has exacerbated the rural-to-urban migration scenario and the tendency for rural dwellers to resort to cutting down trees and burning traditional biomass, all of which contribute to global warming and environmental pollution [4].

Nigeria's energy supply challenges are broadly divided into two parts. The first one is the shortfall in the supply of refined petroleum products such as premium motor spirit (petrol), kerosene, diesel, and aviation fuel, amongst others. The country has four main government-owned petroleum refineries, with a combined refining capacity of 450,000 barrels of oil per day. These refineries have remained largely dysfunctional for many years, resulting in the importation of over 75% of refined products into the country. An estimated 700–800 billion naira was spent on petrol import subsidies in 2008 [9]. Kerosene, mostly consumed by the low-income segment of society, and diesel, mostly used by the commercial and industrial sectors, face more severe and prolonged market shortages than petrol (consumed by the middle class). This is because of lower levels of political pressure on the government from these groups and because of restrictions on public financing of large-scale imports [8].

Blackouts, brownouts (a sudden or unusual drop in electric power supply in a society), and the widespread use of generators for electricity supply are all symptoms of a deeper problem with Nigeria's electricity industry. The now-defunct state-owned Power Holding Company of Nigeria (PHCN), previously called the National Electric Power Authority (NEPA), controlled most of the electricity industry and had failed for three decades to meet even the most basic international requirements for electricity supply [3]. Figure 1.0 shows a significant and increasing trend in power losses in the transmission and distribution networks, and this sheds light on the nature of the dismal track record in electricity delivery in the country. This double-digit percentages in transmission and distribution losses, when compared to what applies in most developed countries, is considered unusually significant. This system's losses represent about five to six times higher than the average seen in most electricity grids that are efficiently operated. Load shedding across all sectors of the economy, and most importantly, the reduced supply to the manufacturing sector creates a compounding situation for industrial growth and the overall economic development scenario. Approximately 20% of the capital invested in manufacturing ventures goes towards developing alternative power sources [16]. As shown in Figure 2.0, percentage increases in Nigeria's overall energy use have been less than desirable and grossly inadequate to meet the growing demand trend.

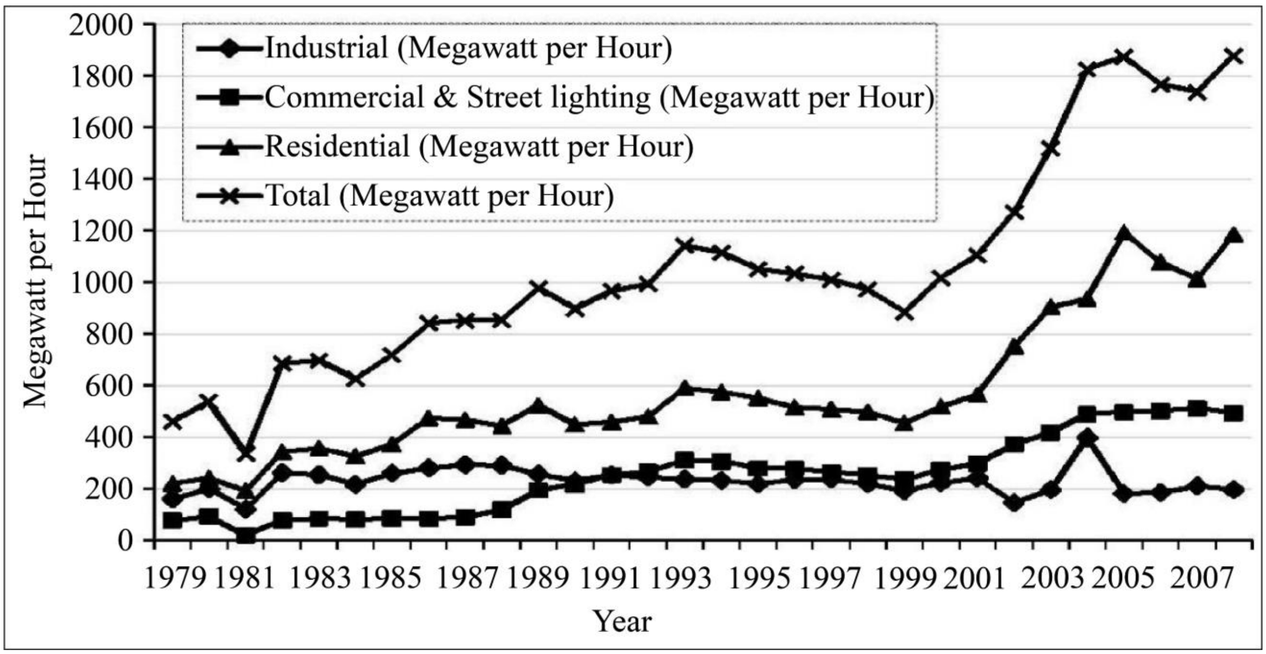

Fig. 1 Indicators of the nigerian power outage from 1970 to 2004

***Source:* [9]**

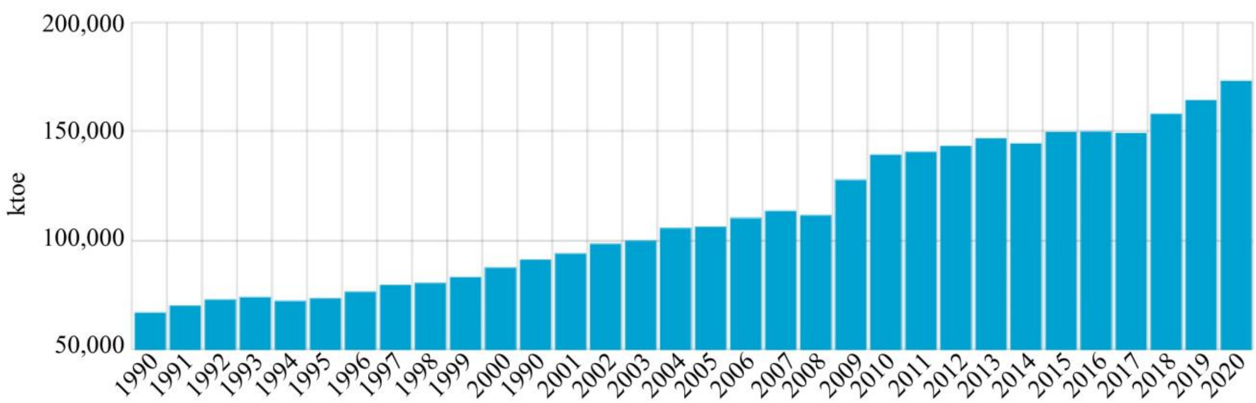

Fig. 2 Chart showing the increase in nigeria's total energy use

Source: Enerdata (2021)

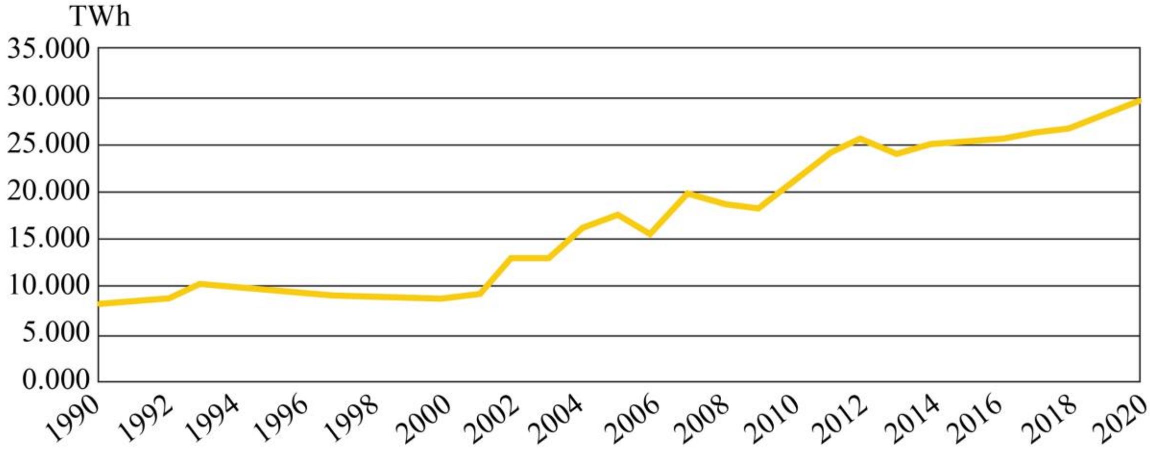

Fig. 3 Electrical Power Used (Terra watt hours)

Source: Enerdata (2021)

Despite the low per capita electricity consumption in Nigeria, estimated at 140 kilowatt-hours per person in 2020, much lower than the global average and almost three times lower than the Sub-Saharan Africa average, the consumption of combined energy sources places Nigeria in a slightly better position. For instance, in 2021, the per capita consumption of all energy sources in the country was estimated at 0.8 t.oe (tons of energy equivalent), one-third higher than the average for Sub-Saharan Africa. As shown in Figure 3.0 below, between 2013 and 2020, power consumption grew at a slower rate than in the past, increasing by about 3% per year compared to around 9% between 2000 and 2012. Since 2000, the residential sector's proportion of total electricity consumption has steadily climbed (from 51% to 58% in 2021), while the industrial sector's share has steadily decreased (from 21% to 14% in 2021).

Electricity consumption, or energy use in general, is crucial for all life forms. Historically, energy consumption has had an overall positive correlation with economic growth, represented by the increase in (GDP) gross domestic product. As stated by **[19]**, energy demand is affected by various variables, including population growth and the economy's composition in terms of GDP and other variables. From 2000 to 2030, the forecast for Nigeria's population shows an increase from 115.22 million to 281.89 million at a 2.86% annual growth rate. As shown in Figure 4.0 below, electricity demand is expected to rise steadily between 2005 and 2030 for all 4 separate growth scenarios (Reference case at 7%, High Growth case at 10%, Optimistic at 11.5% and Optimistic case at 13%). This rise in energy demand is attributable to the robust GDP growth anticipated in Nigeria within the period, together with the expected growth in population.

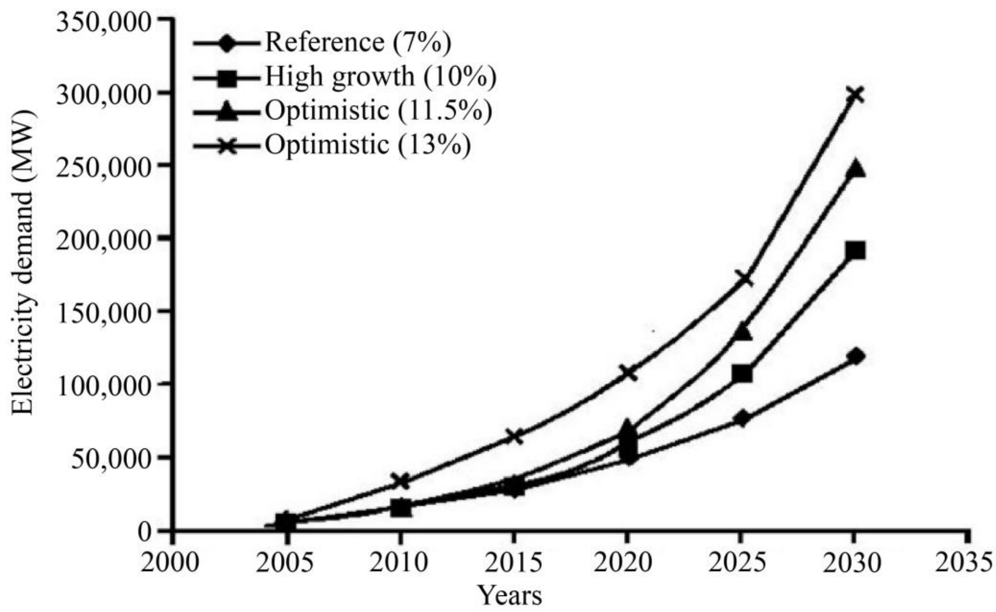

Fig. 4 Nigeria's electricity consumption forecast from 2005 to 2030

Source: CBN (2009)

Generally, neural networks are distributed, massively parallel processors made up of small processing units that have a built-in inclination for encoding and retrieving experiential information [6], [11], [5]. There are three ways in which it is like the brain: (i) training a neural network to perform a set of tasks is like how the brain acquires data from its surroundings through the learning process. (ii) knowledge is generalized after being processed by the brain from specific instances into more abstract concepts that may be applied to new situations. (iii) To the extent that neural networks may change the topology of their connections, this process can be thought of as analogous to the death and rebirth of brain cells. Artificial neural networks (ANN), or variants such as recurrent neural networks (RNN) and others, are a pool of non-linear parallel distributed computing components whose solutions can be estimated by algorithm creation and simulation approach. ANN is widely used in Engineering practice for modeling analysis and forecasting. The development of new network models, which represent different variants of ANN, and the availability of easily accessible ANN software are driving its increased adoption in critical engineering applications [15], [18]. Research efforts have led to the creation of a software development process model for neural network development, even though it is sometimes challenging to deploy the model due to the experimental nature of its construction and the fact that it is often seen as a black box.

2. Materials and Method

One of the primary functions of neurons in neural networks is data processing. As shown in Fig. 5.0, it comprises three main parts: a network of synapses and connecting nodes, a combinational function, and activation functions. The externally applied bias b_k in a neural model can either enhance or dampen the net input to the activation function [5], [11], [13]. The mathematical expression for the connection between the activation potential uk, the output of the combination function vk, the weights owing to the synapses wk, and the bias b_k in a neural model k is (2.1) to (2.2). (2.3). Figure 6.0 depicts a completely interconnected feed-forward network with a lone embedded stratum of neurons, and Figure 7.0 depicts a recurrent network.

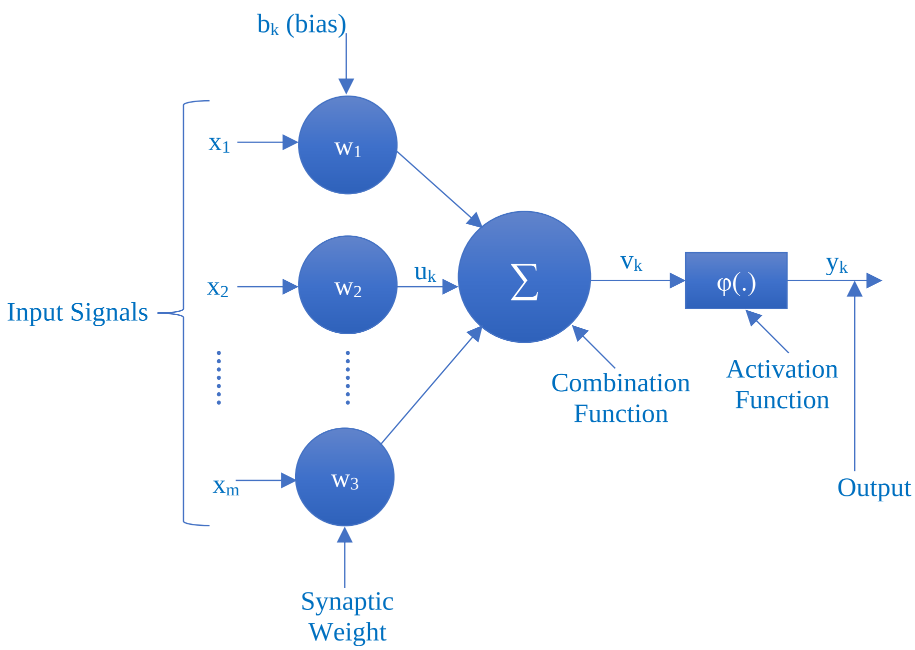

Fig. 5 A Neuronal model with Non-Linear dynamics

$$u_k = \sum_{j=1}^{m} w_{kj} x_j \tag{2.1}$$

$$v_k = (u_k + b_k) \tag{2.2}$$

$$v_k = \sum_{j=0}^{m} w_{kj} x_j + b_k \tag{2.3}$$

$$\text{and } y_k = (v_k) \quad (2.4)$$

Equations 2.1 to 2,4 above represent a non-linear model of a neuron, which is seen in Figure 7.0 and 8.0 below.

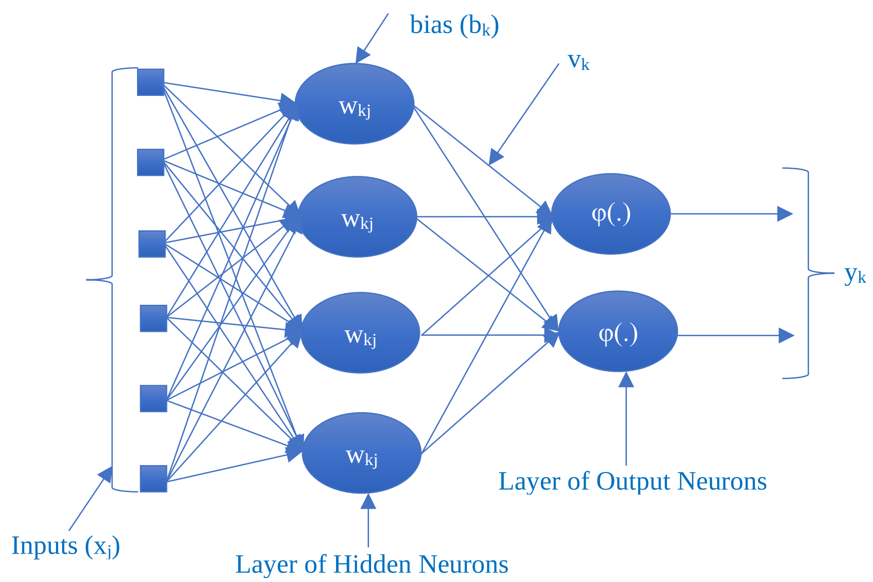

Fig. 6 A Completely interconnected feed forward network

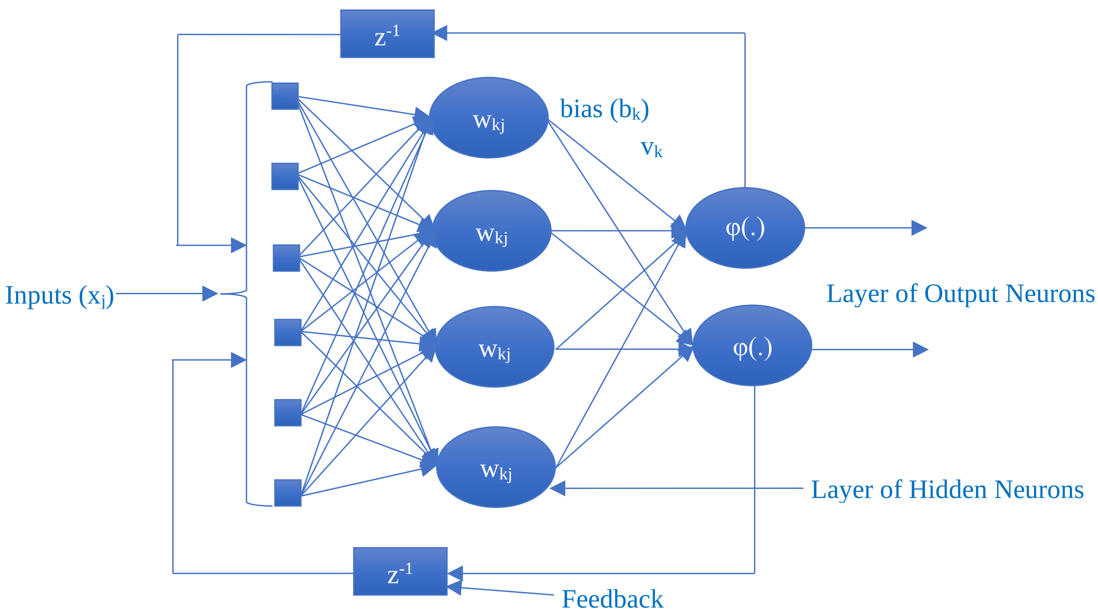

Fig. 7 Recycle output of recurrent networks

2.1. Recurrent Neural Network Long Short-Term Memory Network

Long Short-Term Memory Networks (LSTM) are RNN variants that have the capability to accept input data, process them and learn from the inherent sequence found in the data series. These modeling techniques were initially introduced through the work carried out by **[7]** and have been the subject of several other research efforts by others. With the availability of robust and reliable long-term time series data, LSTMs have the capacity to "learn" the dependencies that exist in the data series.

2.2. RNN-LSTM Model Architecture

RNN neural networks make up an architecture, one of which reads the input data (which is of variable size) and encodes it into a fixed-length numeric vector. The other receives this vector and forecasts (or, in our case, changes) the output data (which is again of variable size), as seen in Figure 8.0. Most studies using this encoder and decoder architecture apply it to sequence-to-sequence transformations, such as translating languages. In those circumstances, a sentence must be incorporated from raw input data (i.e., a sequence of words). The input models used in this study, numerical values, are fed into the LSTM encoder using the input tree embedding layer. Also, an output layer receives the numerical vectors generated by the decoder. It generates the predicted (transformed) output model in its tree form, which is then sent to the post-processing job to build the final output model. An attention mechanism is also a part of the neural network architecture. Attention mechanisms used in encoder-decoder designs are positioned between the encoder and the decoder. This layer enables the decoder to focus more of its attention on regions of the fixed-size vector that is received. In other words, it enables the decoder to give model components a higher value. The attention mechanisms automatically determine which parts of the input models the decoder needs to pay more attention to during the output model generation without any external guidance. This means that they are completely independent when it comes to deciding which parts of the input models are more important.

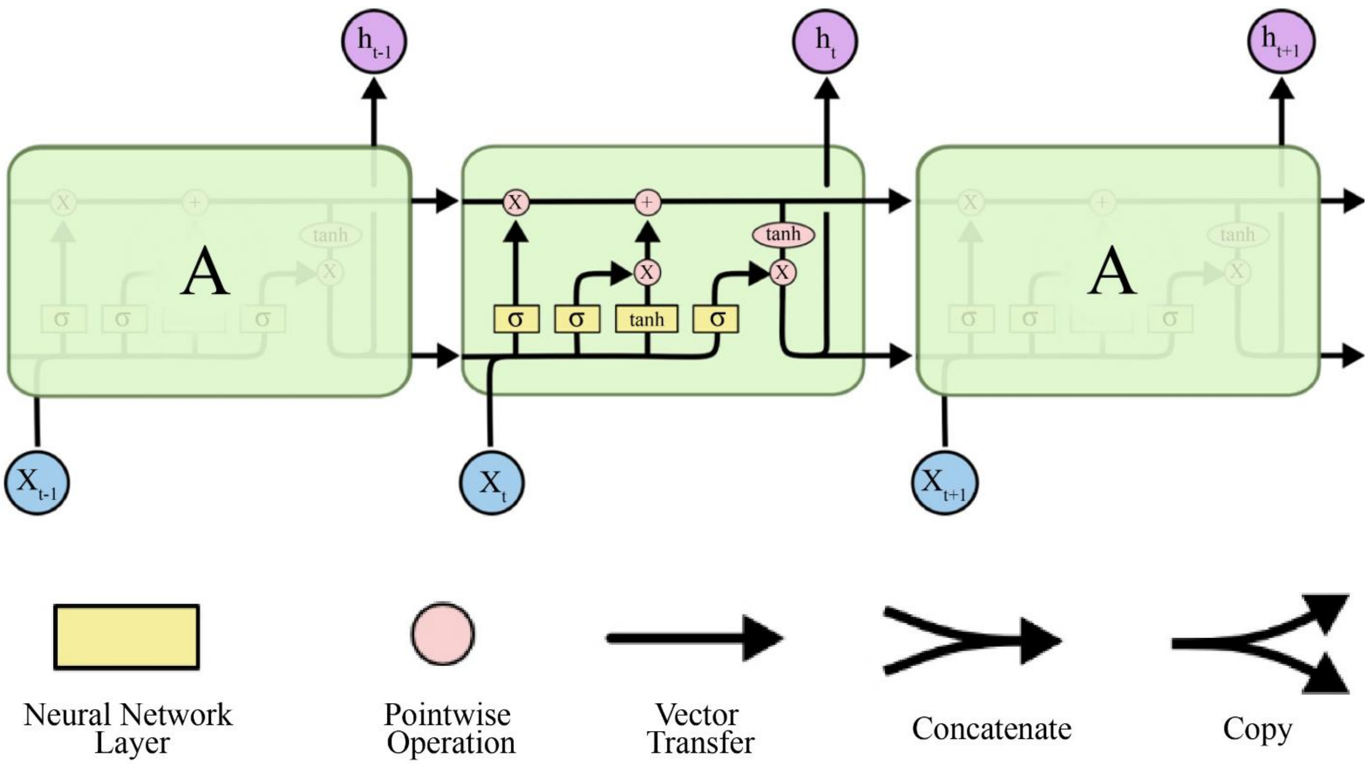

Fig. 8 RNN-LSTM model architecture

2.3. Data Source

This study uses secondary data obtained from both the World Bank and the Nigerian National Bureau of Statistics. This is made up of the independent variable, the annual electricity consumption data in Nigeria between 1990 and 2020, broken down in terms of consumption by three sectors of the economy – commercial, industrial, and residential consumption. The dependent variable, also obtained from the Nigerian Bureau of Statistics, is the Gross Dependent Product (GDP). The economic indices data is presented in Table 1.0 below, while a summary of the electricity consumption data is presented in Table 2.0.

Table 1. Economic Indices over a 30-year time series (1990 – 2020) in Nigeria

Year	Real GDP Growth Rate (%)	Unemployment Rate (%)	Inflation Rate (%)	No. of Jobs created
1990	11.78	3.5	7.5	46720
1991	0.36	3.1	13	67597
1992	4.63	3.4	44.5	108189
1993	-2.04	2.7	57.2	246597
1994	-1.82	2	57	336537
1995	-0.08	1.8	72.8	456349

1996	4.19	3.8	29.3	309745
1997	2.93	3.2	8.5	216162
1998	2.58	3.2	10	193132
1999	0.58	8.2	6.6	225812
2000	5.01	13.1	6.9	109649
2001	5.92	13.6	18.9	169175
2002	15.33	12.6	12.9	105128
2003	7.35	14.8	14	109649
2004	9.25	13.4	15	169175
2005	6.44	11.9	17.9	105128
2006	6.06	12.3	8.5	172140
2007	6.59	12.7	5.4	539490
2008	6.76	14.9	15.1	479265
2009	8.04	19.7	13.9	534228
2010	9.13	21.4	11.8	657952
2011	5.31	23.9	10.3	866532
2012	4.21	27.4	12	955917
2013	5.49	24.7	8	1163766
2014	6.22	25.1	8	1192620
2015	2.79	29.2	9.6	1585139
2016	-1.58	35.2	18.6	1064946
2017	0.82	40.9	15.4	479456
2018	1.91	43.3	11.4	356079
2019	2.27	48.7	12	113328
2020	-1.92	56.1	15.8	65113

Source: NBS/World Bank (2021)

Table 2. Sample of electricity consumption data in nigeria over a 30-years (1990 – 2020)

Year/ Quarter	CONSUMPTION (INDUSTRIES) (MWh)	COMMERCIAL AND STREET LIGHTING (MWh)	RESIDENTIAL (MWh)
1990/Q1	997,897.98	943,687.96	1,955,030.02
1990Q2	867,133.47	820,027.13	1,698,842.97
1990/Q3	180,338.89	170,542.12	353,310.61
1990/Q4	77,900.78	73,668.88	152,619.17
1991/Q1	871,780.19	873,154.70	1,578,276.08
1991/Q2	915,902.02	917,346.09	1,658,154.51
1991/Q3	60,426.36	60,521.64	109,396.25
1991/Q4	497,262.96	498,046.98	900,247.85
1992/Q1	798,511.86	866,220.98	567,726.50
1992/Q2	547,126.58	593,519.70	1,074,179.21
1992/Q3	308,161.62	334,291.91	605,016.85
1992/Q4	574,403.37	623,109.40	1,127,732.02
1993/Q1	385,900.19	506,514.32	962,962.40
1993/Q2	514,424.56	675,209.32	1,283,677.80

Source: NBS/World Bank (2021)

3. Results and Discussion

The accuracy of a recurrent neural network, or any machine learning model, involves studying the level of its correctness, which is measured through validation loss. The accuracy should be as close to 1, and the validation loss should be as near as 0. The accuracy level is measured by the extent to which the model's output matches the expected result or the actual. If there is a strong match, the ability of the model to forecast and transform is considered successful. The data input into the RNN model was randomized to avoid bias in the model. The plots of GDP against randomized date, actual against predicted, are presented in Figure 9.0 below (model output).

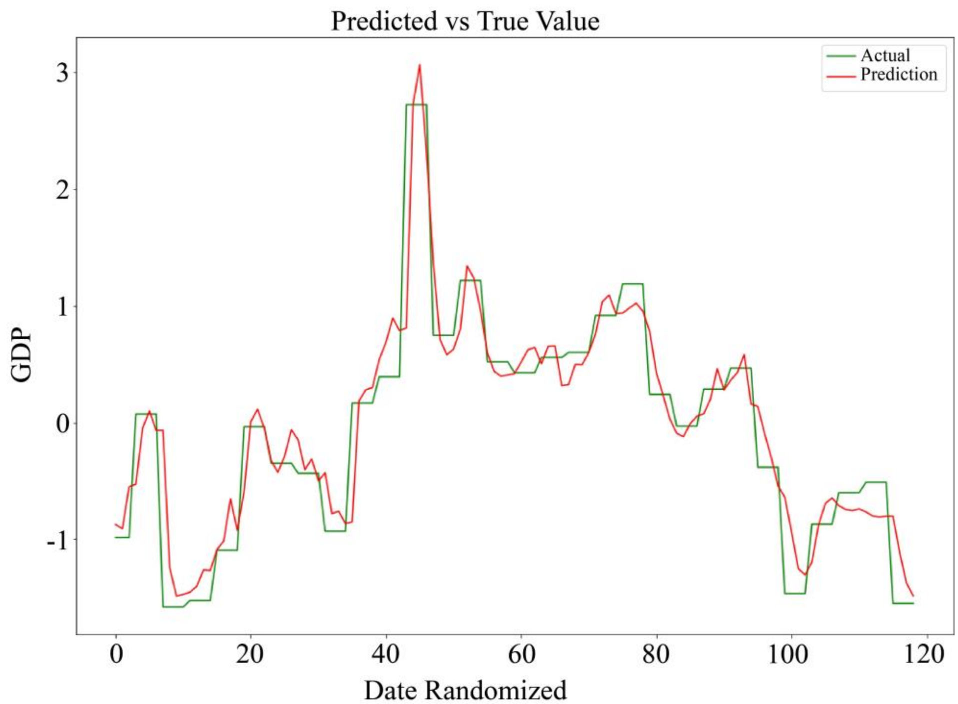

Fig. 9 Actual and predicted GDP numbers from the RNN model

From the above plot, both the actual and the predicted GDP track each other very closely for all the data points. The average difference between the two is 0.03, indicating that the RNN model is a strong and suitable tool for predicting GDP trends over a period given electricity consumption data as the independent variable. The effectiveness of the RNN model in estimating the economic growth in the country is demonstrated by the measurement of R-squared and Root Mean Squared Error (RMSE) validation checks. The R-squared value, which measures the goodness of fit, and Root Mean Squared Error numbers, which indicate the level of accuracy with the model, can predict the actual GDP forecast from the model, are 0.8677 and 0.3464, respectively. Using the recurrent neural network technique has presented an innovative and very accurate tool to forecast the economic growth in the country using electricity consumption data. This forecast, together with the scope of the study, can be extended to cover other macroeconomic indices such as price level (inflation) and unemployment rate, amongst others. The outcome of this study, which involves both a correlation analysis and a forecast of future trends using a feed-forward neural network technique, is a significant improvement over the outcomes from similar studies based on the reviewed literature.

4. Conclusion

Generally, machine learning applications thrive on the availability of very robust time-series data. The outcome of this recurrent neural network (RNN) modelling exercise gives a reliable output, as the predicted value tracks the actual values accurately. Despite the apparent limitation in the scale of the available dataset, the model output was sufficiently accurate regarding the closeness of fit between the actual GDP numbers and the predicted values. The data limitation stems from the fact that the 30-year time-series data, both for the dependent and independent variables, were rendered in a quarterly format. A more elaborate breakdown of the data into either a monthly or weekly dataset (for the electricity consumption, for instance) would create an enormous amount of data, which would aid in the training of the model to help achieve a higher level of accuracy with the forecast. However, despite the above limitation, the R-squared number for the RNN model is relatively high and generally within the acceptable region. The RMSE, which measures the average difference between the model prediction and the actual values and approximates the accuracy level of the model, is also reasonably good. Typically, a lower RMSE value is a good indication of the higher accuracy of the model. Based on the outcome of this study, the RNN model is good and considered very reliable in predicting the economic growth parameter (GDP) in Nigeria over a period of time based on the impact of electricity consumption. The input data (the independent variable) for the RNN model is the 30-year electricity consumption data, and the model output (the dependent variable) predicts the GDP growth rate over the period. As stated earlier, the model output (predicted values) tracks the actual GDP values with a high accuracy level. With this, the model is able to establish the correlation between electricity consumption and economic growth in the country and to make a forecast of future GDP growth profiles in the country based on certain electricity consumption scenarios. This is a significant outcome of this study, as it creates opportunities to model diverse economic growth potentials or realities, which in turn could be used as inputs for different government policies.

As stated earlier, there is an enormous electricity supply gap in Nigeria, as demand far outpaces supply. To stimulate economic growth in the country, Nigeria must substantially increase its electricity supply to its citizens in a cost-competitive way. This will require significant investments to help increase installed generation capacity, upgrade the transmission and distribution networks, and improve service quality. This is very relevant for the country to achieve sustainable development, protect its environment and foster social harmony. To keep up with the rising demand for electricity across the country, a diverse portfolio of fossil and renewable energy sources and enhanced end-use efficiency will be essential. Meeting future demand will require increased investment in technology, the creation of decentralized non-grid networks, various energy-supply systems, and providing different energy services at competitive prices.

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