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Study and Analysis of Abatement of Sulphur (Iv) Oxide Emission in a Chemical Plant in Rivers State Nigeria, A Case Study of Notore Chemical Industries

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Abstract

This study examined electricity generation and Sulphur (iv) oxide ($S0_2$) emission abatement of a known fertilizer industry in Nigeria. The specific objectives of the study are to: determine the trend analysis of trend analysis aggregate Green House Gas emissions in Nigeria, evaluate the effect of $S0_2$ gas emissions on energy performance in Nigeria, examine the effect of $S0_2$ gas emissions on electricity generation in Nigeria and analyse the trend of $S0_2$ gas emissions against Gross Domestic Product emission index in Nigeria. The data used for the study was extracted from National Green House Gases Inventory Report over a period of 18 years. The greenhouse gases and other parameters that were extracted from the statistical bulletin include; $S0_2$ Emission, CH_4 emission, $N0_2$ Emission (Gg) $C0_2$ emission, (Gg), Energy consumed, Gross Domestic Product emissions index and Electricity generation in Nigeria. The E-view version 12 software was used to analyse the data. The result of the study and analysis revealed that a unit increase in $S0_2$ emission will lead to 0.000853unit increase in $C0_2$ emission. Unit increase in $S0_2$ emission led to 1.19E-05unit increase in CH_4. Similarly, the result revealed that a unit increase in $S0_2$ emission will lead to 0.005395unit increase in $N0_2$ emission. Energy consumed had a significant positive relationship with $S0_2$ emission. The result of the study showed that a unit increase in $S0_2$ emission will lead to 0.001426unit increase in Energy consumed. Also, the Gross Domestic Product Emission index recorded a negative relationship with $S0_2$ emissions in the country.

1. Introduction

Adequate power supply is an unavoidable prerequisite to any nation's development. Electricity generation, transmission and distribution are capital-intensive activities requiring huge resources of both funds and capacity. In Nigeria funds availability is progressively dwindling, as such, creative and innovative solutions are necessary to address the power supply problem [1]. Nigeria has an estimated 176 trillion cubic feet of proven natural gas reserves, making the country

one of the top ten natural gas endowed in the world and the largest in Africa. Natural gas is a natural occurring gaseous mixture of hydrocarbons gases found in underground reservoirs. It consists mainly of methane between (70% - 95%) and small percentage of methane, propane, butane, pentane and other heavier hydrocarbons with some impurities such as water vapour, sulphides, carbon dioxides, etc.

Generation of electricity for the production of fertilizers is associated with the pollution of the environment with Green House Gases like $S0_2$. Notore Chemical Industries Plc is a- fertiliser and agro-allied companies in Nigeria. Aside from supplying premium fertilisers to farmers, they also educate farmers on the best practices for farming and how to enrich the soil for optimum results across the country. Notore operates a functional fertiliser plant in Port-Harcourt located at Onne sea port. This ensures the effective shipment and fertiliser distribution across the country. Aside from this, they also produce Ammonia and NPK fertiliser. The air emissions of sulphur dioxide (SO_2) and its environmental and health impacts from the consumption of refined petroleum products with nonuniformity in sulphur contents in Nigeria is an issue of national concern. Significant amounts of SO_2 particles -are released to the air globally, due to combustion characteristics of various engines and a widespread use of fuels with nonuniform qualities in terms of sulphur levels. Sulphur is chemically bonded to the hydrocarbons of the fuel and during combustion; most Sulphur is oxidized to SO_2. Sulphur, which is mostly oxidized to SO_2 during combustion, is a major constituent of the primary particles in the exhaust from gasoline and diesel powered engines from the combustion of fuel. The annual average global SO2 emission was estimated to be 1,561,100tons/km^2 and annual SO2 emission of 190,000 tons/km^2 for Nigeria [2].

Zhang and Wang [3] in their paper, developed a fast suspension bed (FSB) flue gas desulfurization (FGD) scrubber aiming for removal efficiency as high as those of wet scrubber with effective cost. With an innovative flue gas distribution apparatus, this FSB scrubber can enhance both gas-liquid and gas-solid reaction. Also, this scrubber can prevent choking due to lime slurry depositing onto the scrubber inner surface. They investigated the effect of various operating parameters including Ca/S ratio, approach to saturation temperature, flue gas flow rate and slurry particles diameter and distribution on SO_2 removal efficiency. Furthermore, mechanism of desulfurization reaction was examined. Saturation temperature and Ca/S ratio have significant influence on SO_2 removal efficiency. Also, it was examined that SO_2 removal efficiency increases significantly with decrease of saturation temperature and increase in Ca/S ratio. The optimal operating parameters were determined by estimating economy and safety aspects of the FSB-FGD. They found that, the optimal approach to saturation temperature is about 10^0C, the optimum Ca/S ratio 1.5 and the optimal slurry diameter is 50μm. Also, SO_2 removal of this innovative FSB-FGD process is higher than 90%.

In their paper, Dzhonova-Atanasova *et al*. [4] studied the method of Wellman-Lord to remove SO_2 from flue gases of combustion system. In this method, the absorption of sulphur dioxide takes place with sodium sulphite solution to form sodium bisulphite as a product. In a packed absorber, sulphur dioxide is absorbed by sodium sulphite and the resulting solution is sent to an evaporator. In the evaporator, sodium sulphite gets dissolved in the water by condensation of steam that gets evaporated with SO_2. This regenerated sodium sulphite solution can be sent back to the absorber. In this paper the authors have compared Wellman-Lord method with other basic methods of flue gas desulfurization and they found that this method is economical as compared to the other methods. They have also mentioned various techniques to improve the existing Wellman-Lord method. Various solutions were proposed to substantially reduce the steam consumption of the method on the basis of a significant increase of the SO_2concentration in the saturated absorbent. A new technology was introduced, on the basis of the improved method of Wellman-Lord, which has the following advantages over the typical Wellman-Lord method: lower steam consumption with about 60 %; also, the heat for evaporation of the solution can be utilized in the condenser for heating district heating water; lower capital costs.

Gao *et al*. [5] investigated two methods: a plasma technology of Corona Radical Shower(CRS) and a semi-dry flue gas cleaning technology for simultaneously removing multi pollutants from flue gas. In this research, the simultaneous removals of SO_2 and NO_x using CRS system was achieved through two processes according to the different additional gases; using NH_3 as additional gas and using O_2 as additional gas. In semi-dry flue gas cleaning technology for multi pollutants simultaneous removal, acidic substances such as SO_2, HCl, HF are removed by $Ca(OH)_2$-based absorbent from flue-gas and this is then converted into saline material. In semi-dry flue gas cleaning technology, composite absorbent with multi-component and high activity combined with multistage humidifier were used to control multi-pollutants simultaneously. In this paper, it was observed that CRS of ammonia and CRS of oxygen as additional gas can obtain high $DeSO_2$ removal efficiency. While, the semi-dry flue gas cleaning technology can achieve high multi-pollutants removal efficiency through multistage humidification and improving additive.

In their paper, Özyuğuran and Ersoy-Meriçboyu [6] investigated and compared the desulfurization efficiencies of different hydrated lime and dolomite sorbents. Sulfation experiments were performed at 338 K. A thermobalance was used to record the weight increase of the sorbents during their reaction with SO_2. Total sulfation capacity and conversion values of the hydrated lime and hydrated dolomite sorbents were examined. The relation between the total sulfation capacities of hydrated lime and dolomite sorbents with their surface areas and mean pore radius was also determined. It was observed that total sulfation capacities of hydrated sorbents increased with the increase in their surface areas and the decrease in their mean pore radius. Thus, it was concluded that the physical properties of sorbents have great influence on their sulfation properties.

In their paper, Fellner and Khandl [7] compared different methods for evaluation of limestone reactivity and showed that the reactivity is related to the porosity of limestone grains. Eight samples of limestone were investigated and their chemical composition was analyzed using classical analytical methods. Also, the degree of conversion of limestone as a function of reaction time was plotted for the reaction of limestone suspension with 0.5 M-H_2SO_4 and 0.5 M-H_2SO_3. Half-time of the reactions for examined samples was also presented. It was observed that there is a linear dependence between both sets of results. Therefore, the tests carried out with sulfuric acid are equivalent to those realized with sulfurous acid. It was concluded that the reactivity of limestone powder depends remarkably on the reaction surface of samples. It was seen that there is a correlation between apparent porosity and kinetics of the reaction.

In their paper, Akin Folarin *et al*. [8] explained the removal of SO_2 absorbed into sulfuric acid solution from simulated flue gases on platinum expanded mesh anode as three dimensional packed bed electrode in a batch mode. In this study, SO_2 was converted to sulfate by electrochemical oxidation while it was being absorbed in the sulfuric acid solution. The effects of various parameters such as current density, gas flow rate, and initial SO_2 concentration were determined. It was found that the investment and energy costs can be kept lower in electrochemical absorption. Furthermore, no chemicals are required in this process. Therefore, electrochemical oxidation of SO_2 can be considered as a process in which no waste is produced. Also, it was seen that this method gives a removal efficiency of 100% which meets the regulations requirement. Hence, the results of this investigation have shown that absorption and electrochemical removal of SO_2 can be performed on an expanded mesh platinum anode in one step.

Guo and Gao [9] in their work, aimed at finding the simultaneous absorption characteristic of SO_2 and NO_2 by limestone slurry, which is the most widely used absorbent in wet flue gas desulfurization system. Further, they determined the effect of inlet NO_2 concentration on SO_2 removal and found that SO_2 removal efficiency decreased when NO_2 concentration was increased from 100 ppm to 300 ppm. They also examined the effect of inlet SO_2 concentration on NO_2 removal and found that when inlet SO_2 concentration was increased from 200 ppm to 1000 ppm, NO_2 removal efficiency increased to 57%. While investigating the effect of temperature they observed that when reaction temperature was increased from 25^0C to 55^0C, both the removal efficiency of SO_2 and NO_2

decreased about 10%. Furthermore, SO_2 removal efficiency increased with increasing O_2 content. For the SO_2 removal process in their study, the maximum removal efficiency of SO_2 was found to be 90%–96%.

Mehrara *et al*. [10] introduced a new technique to reduce emissions in air by using amine based absorbers to reduce concentration of SO_2. In their experiments, various parameters such as SO_2 concentration, column pressure, temperature of absorption are investigated in a steady state condition. They changed the proportion between sulfuric acid and amine to adjust the pH value. They found that desulfurization efficiency increased with the increase in ph. The experimental result indicated that the efficiency of absorption into amine solution decreases with an increase in SO_2 concentration of the inlet gas. Also, results showed that the best performance was achieved at 110^0C. Furthermore, the results showed that an increase in SO_2 concentration from 2400 to 7800 decreases the performance of absorption by about 34%, and desulfurization efficiency increases very smoothly with increase in G/L value for more absorbent and more contact area in the scrubber. Thus, they categorized the experiment as a selective highly efficient desulfurization process.

Krzyżyńska *et al*. [11] conducted bench and pilot scale studies on the simultaneous removals of SO_2, NO_x, and mercury from coal combustion flue gas using a limestone based wet flue gas desulfurization (FGD) scrubber. This bench-scale experimental apparatus made use of a flow-through gas-liquid impinger to simulate a wet Flue Gas Desulphurization scrubber. Simultaneous removal of SO_2, NO_x, and Hg was tested at 55^0C by using SO_2 concentration of 1,500 ppm. The effect of SO_2 concentration on the simultaneous removal of NO_x, SO_2, and Hg was performed. It was observed that the lack of SO_2 in flue gas causes a dramatic decrease in Hg, NO, and NO_x removal efficiency. Also, increasing the temperature accelerates the reaction rate, but decreases gas solubility in the liquid. Their research demonstrated that sodium chlorite could be used as an effective additive for the simultaneous removal of SO_2, NO_x, and Hg in wet scrubber simulators fed by limestone slurry in bench- and pilot-scale systems. Also, they observed that, all bench-scale experiments resulted in SO_2 removal efficiency near 100%.

Liu *et al*. [12] conducted a study for developing a novel and green process by designing a series of electrochemical reactions through SO_2 absorption-and-conversion process. The study that they conducted focused on the chemical and sustainable fundamentals and the pH optimization for the SO_2 oxidation. In this electrochemical process, the SO_2 was designed to be absorbed into aqueous solution along with alkaline, then oxidized to sulfate, and then transformed into bisulfate. The anodic reaction uses H_2O to supply H+ ions which is scavenged by O_2 from air in the cathodic reaction. The H+ scavenging increases the SO_2 absorption and its further oxidation. Consequently, the SO_2 conversion forms $NaHSO_4$ electrochemically as a sulphur-containing product. $NaHSO_4$ is a valuable chemical and widely used as an additive and as a replacement of H_2SO_4 in industry for pH adjustment and catalytic reactions. The results showed that alkaline condition at pH > 7.0 is beneficial to the SO_2 absorption. This new process can fully comply with the principles of green chemistry and seems feasible. If flexibly applied in a wet Flue Gas Desulphurization process for SO_2 removal, this could be an environmentally-sustainable technique. This new process immobilizes the SO_2 waste in the form of non-calcium product by means of a cheap and non-toxic material, and thereby avoids the concern over any secondary pollution.

In their paper, Deshwal and Lee [13] chose euchlorine solution for the removal of $NO_x$and SO_2 from flue gases in a lab-scale bubbling reactor. They carried out a number of preliminary experiments to assess the physical characteristics, including the gas phase and liquid phase mass transfer coefficients and their correlation equations were established. They found that at high euchlorine feeding rates, SO_2 and NO were removed effectively. Removal efficiency around 100% and 72% was observed for SO_2 and NO_x respectively at a scrubbing temperature of 45 degree Celsius. Also, the oxidizing and absorption ability of euchlorine was not affected by pH, thus making it a superior oxidative absorbent as compared to sodium chlorite. Sulphate, nitrate and chloride are the byproducts of the reaction which are not hazardous materials, thus causing no secondary pollution.

The mass balance of these ions was confirmed. Hence, euchlorine, generated from chlorate-chloride process will not only reduce the cost, but also solve the problem of pH adjustment encountered while using sodium chlorite.

Ljutzkanov *et al*. [14] in their paper, presented the results of the investigations connected with creating a unit for the oxidation of $CaSO_3$ during the removal of SO_2 from flue gases, and drying of the product to gypsum for building purposes. To increase the absorption rate, the hydrocyclone block for separation of the bigger crystals was removed. Also, due to high capital investments the centrifuge used for separation of solution was eliminated and the sulphites in the slurry were oxidized completely dry. In addition to this, $CaSO_4.2H_2O$ was dried in a spray dryer without preliminary separation of the liquid phase. This required almost complete oxidation of the $CaSO_3$ to $CaSO_4$ in the oxidizer. The design of a new oxidizer was proposed, which was divided into 4 chambers by vertical partitions with regular distribution of air by perforated horizontal tubes in the slurry. The air distribution using various plates with different orifice diameter and catalyst concentrations were investigated. The results showed that by injecting water with the air every 30 minutes, the process can be carried out continuously without stopping for cleaning of the orifices. It was seen that at Fe ion concentration of 0.15g/l and Mnion concentration of 0.57 g/l, over 99% of the slurry got converted to gypsum for 9 hours. Thus, this data was used for designing an oxidizer for purification of flue gases from SO_2.

The data for equilibrium partial pressure of SO_2over the slurry, needed for the selection of absorbers and their calculation at temperatures at which the industrial apparatuses for the absorption of SO_2 from flue gases operate, was presented by Ljutzkanov *et al*. [14] Up until that time, there were installations for carrying out SO_2 absorption with $CaCO_3$ slurry only for big capacity boilers. Also, the equilibrium data was available in literature only for a temperature of 25 degree Celsius. Thus, experiments were carried out for obtaining equilibrium data for the partial pressure of SO_2 over slurry containing $CaCO_3$, $CaSO_3$ and $CaSO_4$ at different temperatures. It was found that the increasing of the temperature from 25 degree Celsius to 45 degree Celsius leads to about 3 times increase in the partial pressure of SO_2 at lower partial pressures. When it increases to 60 degree Celsius, the increase in partial pressure is about 10 times.

Dzhonova-Atanasova *et al*. [4] presented a review of the main principles, technological solutions and study results on flue gas desulfurization (FGD) with an emphasis on wet limestone gypsum technology, which is the most common FGD process. There are about 20 different kinds of SO_2 removal techniques available. For wet limestone-gypsum technology, data shows that their SO_2 removal efficiency varies from 84 to 99%. Various methods of wet flue gas desulfurization were investigated. Also, a Computational Fluid Dynamics (CFD) model for a flue gas desulfurization plant of wet scrubber type, and its application to an operating plant was presented. The effects of adding an organic acid while using $CaCO_3$ as sorbent for SO_3 removal, has also been examined. Investigations were made to find out the effects of different parameters on SO_2 removal efficiency. The degree of desulfurization, residual limestone content of gypsum, liquid phase concentrations were measured while varying parameters like concentration of SO_2, temperature, etc. Though the present world level of removal efficiency of wet FGD technology is about 95%, the amount of SO_2 discharged in the atmosphere is huge. Thus, these findings help in the selection of apparatuses and equipment and examining new solutions.

Srivastava and Jozewicz [15] in their paper, worked to develop nonstationary models of wet calcite flue gas desulphurization process and use these models to optimize this process with respect to investment and operating costs. Non-stationary Flue gas desulphurization models were developed for spray scrubber and falling film absorber and comparative results were obtained. It was observed that falling film absorber offers less expensive operation as compared to spray tower. The rate of scaling for different materials was also investigated in a continuous small pilot flue gas desulphurization arrangement. New facts were experimentally developed that allowed the consideration of falling film absorbers that could avoid scaling problems in long term operation.

The equipment were critically analyzed and its integration led to reduction of tanks, valves, pumps, pipes etc. and hence offered significant potential for investment and operating savings. Also, according to the risk analysis, the risk of failure of the entire system also decreased due to the diminished number of the equipment.

Unguresan and Jantschi [16] in their paper, investigated a number of methods used in order to remove sulphur and sulphur oxides from fuels before combustion and from the resulted gas after combustion. The advantages and disadvantages of the most important systems of gas absorption were explained. The electrochemical methods of desulphurization were also investigated. The authors studied the feasibility of electrochemical removal of sulphite ions arising from the absorption of SO_2 in an aqueous electrolyte. Various parameters such as removal efficiency, current efficiency, and energy consumption were determined at different initial sulphite ion and electrolyte concentrations and applied currents. Thus, the electrochemical method can successfully be used for SO_2 removal from flue gases. It was observed that the chemical methods for SO_2 removal involve obtaining big quantities of waste products and are very expensive. On the other hand, the electrochemical methods are not polluting and hence are used more often than the chemical methods. These processes do not consume much energy and the rate of the processes can be rigorously controlled.

Xiuping *et al*. [17] in their work, investigated the SO_2 absorption technique with sodium citrate by using the rotating packed bed (RPB) and the effects of various operating parameters, like the rotation speed of RPB, liquid-gas ratio, inlet gas flow rate, inlet concentration of SO_2 in flue gas, sodium citrate buffer concentration and initial pH of absorption solution, on the SO_2 concentration in the absorption solution or removal efficiency ofSO_2 were determined. They also obtained the appropriate Liquid-Gas ratio. The investigation showed that increase in concentration of SO2 decrease the efficiency, while higher the concentration of citrate higher the efficiency. It also showed that, higher pH may affect the absorption process significantly. Higher rotation speed of (RPB) *N* is favorable to increase the absorption rate, resulting in higher absorption efficiency and absorption capability of solution and shorter operation time.

Kanee *et al.* [18] study investigated the particulate Matter-Based Air Quality Index Estimate for Abuja, Nigeria: Implications for Health. The study was designed to measure the level of suspended particulate matter (PM2.5 and PM10) for dry and wet seasons, compute the prevalent air quality index of selected locations in Abuja with possible health implications. Suspended particulate matter (PM2.5 and PM10) was assessed using handheld aerosol particulate sampler. The US Oak Ridge National AQI was adopted for the eleven (11) locations sampled and monitored. The study results showed that the air quality of the selected areas in Abuja were generally good and healthy. Dry season, assessments, showed 15 - 95 µg/m3 and 12 - 80 µg/m3 for PM2.5 and PM10, respectively. While in wet season, 09 - 75 µg/m3 and 07 - 65 µg/m3 were recorded for PM2.5 and PM10. However, at Jebi Central Motor Park, there was light air contamination with AQI of 42 for dry season and 31 for wet season. Other locations had clean air with AQI ≤ 11. It is revealed that clean air exists generally during the wet season. Comparing study outcome to other cities in Nigeria, residents of Abuja are likely not to be affected with health hazards of particulate matter pollution. Nonetheless, the high range of PM2.5 and PM10 (fine and coarse particles) ratio evaluated i.e., 1.06 - 1.79 was higher than the WHO recommended standard of 0.5 - 0.8. This ratio remains a health concerns for sensitive inhabitants like pregnant women and their fetus as well as infants below age five whose respiratory airways are noted to have high surface areas and absorption capacity for fine particulate matter. Vegetation known to absorb suspended particulate matter should be planted across Abuja metropolitan areas and air quality monitoring stations installed at strategic locations for continuous monitoring and evaluations. Air Quality Index (AQI) as demonstrated in this study showed how relatively clean or polluted the boundary layer environment of any location can be. In recent years, urban air quality in developing countries such as Nigeria has continued to degenerate and this has constituted a major environmental risk to human health. It has been shown that an

increase in ambient particulate matter (PM10) load of 10 µg/m3 reduces life expectancy by 0.64 years.

Wang and Corbett [19] investigated the costs and benefits of reducing SO2 emissions from ships in the US West Coastal waters. The costs and benefits of reducing SO2 emissions from ships in the US West Coastal waters. Potential costs and benefits of policy options for reducing offshore ship pollution are examined using a meta-analysis of studies synthesized regionally for the US West Coast. Net benefits of reducing SO2 emissions from cargo ships in the US West Coast waters are found to range between $98 million and $284 million, annually; the benefit–cost ratio varies between 1.8 and 3.36, depending on the size of the control area and the sulfur content limit. The results show that about 21,000 tons of on-land equivalent SO_2 emissions or about 33% of $S0_2$ emissions from all mobile sources in California in 2005 can be reduced annually if the US West Coast exclusive economic zone is designated as an International Maritime Organization-compliant Sox emission control area (SECA) with fuel-sulfur content not exceeding 1.5%. The analysis demonstrates that designating this area reduces more emissions than establishing a smaller zone at a lower but favorable benefit-cost ratio. Control measures that require 0.5% low-sulfur fuels reduce more SO_2 emissions, and also may have higher net benefits. Technological alternatives may achieve benefits of emissions reductions on the US West Coast across higher ranges of potential fuel prices. Combinations of fuel switching and control technology strategies provide the most cost-effective benefits from SECAs on the US West Coast and other world regions. From the available literature, it was obvious that that there are limited studies that captured the study on SO_2 emission abatement on electricity generation of selected fertilizer industries in Nigeria. Therefore, this study is poised towards filling the gap by examining the trend analysis of trend analysis aggregate Green House Gas emissions in Nigeria by focusing on the effect of $S0_2$ gas emissions on energy performance in Nigeria and the trend of $S0_2$ gas emissions against Gross Domestic Product emission index in Nigeria.

2. Methodology

2.1 Research Design

In this study, the *ex post facto* research design methodology was adopted. This methodology a "systematic empirical enquiry in which the researcher does not have direct control of independent variables because their manifestations have already occurred. This method measures the impact of events after the events have occurred. The advantage of this method is that it deepens managerial decisions against the future as it helps in many cases to point to the direction of future events.

2.2 Materials

The materials used for this study comprised of published data from National Green House Gases Inventory Report over a period of 18 years. The greenhouse gases and other parameters that were extracted from the statistical bulletin include; S02 Emission, CH_4 emission, N02 Emission (Gg) $C0_2$ emission, (Gg), Energy consumed, Gross Domestic Product emissions index and Electricity generation in Nigeria.

This GHG inventory used in this study as sourced from National GHG Inventory Report encompassed the whole Federal Republic of Nigeria, and estimated were calculated at the national level. The national GHG inventory comprised of the estimates for the four IPCC sectors, Energy, Industrial Processes and Product Use (IPPU), Agriculture, Forestry and Other Land Use (AFOLU), and Waste. However, due to a lack of Activity Data (AD) in some cases, the categories and subcategories have not been fully exhausted. The coverage of activity areas is mentioned in the report's completeness section. The GHG inventory covers direct GHG emissions such as carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O). Additionally, estimates of the GHG

precursors oxides of nitrogen (NO_X), carbon monoxide (CO), non-methane volatile organic compounds (NMVOCs), and sulphur dioxide (SO_2) were possible when AD were available.

2.3 Sources of Data

Data to be used in this study is a secondary time series obtained from National GHG Inventory Report NIR1 2000 - 2017 Statistical Bulletin. Secondary data is the data that have been already collected by and readily available from other sources. This time frame is selected due to availability of data. Emission inventories are the foundation of air quality management. They are developed using emission factors (EFs) and associated activity (A) information. Emission factors are the mass of pollutant emissions released per unit of the associated process variable. Activities are the related process variable, such as mass of fuel consumed or output produced. The emissions (E) are then calculated as:

Emission pollutant = Activity x Emission Factor pollutant
Or

$$E = A \times EF \quad 1$$

Where
E = emissions, in units of pollutant per unit of time
A = activity rate, in units of weight, volume, distance or duration per unit of time,
EF = emission factor, in of pollutant per unit of weight volume distance or duration

2.4 Evaluation Methods

The study will be evaluated using the R^2, F-test and t-test to evaluate the estimates.

Decision Rule:

A priori suggests that the closer the Durbin - Watson statistics is to 2, the less likely is the presence of autocorrelation. However, a more reliable test suggest that if $d_u < d < 4 - d_u$ then there is the presence of autocorrelation but if otherwise, autocorrelation is said not to exist (Nwaobi, 2001).

a. T-Test:

This is used to test for the statistical significance of the individual regression co-efficient. A two – tailed test is conducted as 5% level of significance. When this is done the computed t-ratio (t_{cal}) is compared with the theoretical t-ratio t_{tab}.

Decision rule

If $t_{cal} > t_{tab}$ reject null hypothesis otherwise accept. Where t_{cal} is calculated test statistics while t_{tab} means Test statistics from statistical table.

b. F Test:

This measures the overall significance of the entire regression plane. The explanatory variables actually have a significant influence on the dependent variable. It is done by comparing the computed F ratio (F_{cal}) is higher the critical F value (F_{tab}) at k-1, n-k degree of freedom and 0.05 level of significance.

Decision rule

If $F_{cal} > F_{tab}$, reject the null hypothesis otherwise accept it.

2.5 Estimation Technique

2.5.1. Trend analysis of combined gas emissions" The trend analysis was carried out using graphical methods. This method was able to show the trend of the various data collected over the years of study.

2.5.2 Relationship between $S0_2$ emissions, energy and electricity generation using ordinary least square method regression analysis

The technique adopted for evaluation of the model is the multiple linear regression method of Ordinary Least Square (OLS). This choice of method is necessitated by the nature of the study which

in this case is an analysis of relationship among variables. The OLS was chosen for estimation because of the following reasons; The OLS is fairly easy to compute as compared to econometric methods; the mechanism of the OLS is simple to comprehend and interpret; finally, the parameters estimated by the OLS methods have some desirable optical properties that produces Best Linear Unbiased Estimators (BLUE). Finally, the effect of N02 emission on energy sector performance in Nigeria and the effect of NO2 emissions on electricity generation in Nigeria was examined with the aid of graphs to depict their relationship.

3. Results

Table 1: of aggregate gas emission, energy, electricity generation and GDP emissions index in Nigeria

Year	$S0_2$ Emission	CH_4 emission (Gg)	$N0_2$ mission (Gg)	$C0_2$ emission (Gg)	Energy	GDP emissions index	Electricity generation
2000	41	148,086	19,822	296,508	37,253	100.0	2,517
2001	54	155,463	20,593	311,818	49,593	99.2	3,892
2002	52	143,306	20,906	317,288	51,963	84.9	7,233
2003	53	157,217	21,706	331,479	59,250	83.8	7,640
2004	47	167,207	21,835	335,562	59,399	78.9	11,799
2005	56	169,860	22,930	356,009	75,819	77.5	19,877
2006	48	169,310	23,681	358,165	74,280	73.4	23,790
2007	44	167,647	24,300	368,726	80,654	70.0	28,732
2008	52	164,984	25,186	379,227	88,685	66.6	31,068
2009	46	160,906	26,067	376,174	80,258	61.0	32,137
2010	50	181,339	27,124	387,708	87,808	59.8	33,175
2011	51	180,098	27,032	396,498	91,585	57.5	33,175
2012	52	184,422	27,907	404,999	94,844	56.4	35,789
2013	67	178,569	29,119	425,326	109,675	54.2	27,826
2014	67	183,221	29,623	445,917	125,005	53.1	33,657
2015	61	187,304	30,071	459,266	133,225	53.1	43,481
2016	64	177,917	31,245	452,099	124,022	52.7	45,112
2017	68	182,686	32,614	462,884	131,196	53.7	47,653

Table 1 showed the aggregate gas emission, energy, electricity generation and GDP emissions index in Nigeria. Emissions of indirect Greenhouse gases (GHG) and SO_2, have also been estimated and reported in the inventory. Indirect GHGs have not been included in national total emissions. Emissions of these gases for the period 2000 to 2017 are given in Table 4.1. Emissions of NO_x increased from 275 Gg in the year 2000 to 495 Gg in 2017. CO emissions also increased from 7,693 Gg in 2000 to 10,959 Gg in 2017. Likewise, for NMVOCs from 1480 Gg in 2000 to 2031 Gg in 2017 whilst emissions of SO_2 varied between 41.6 Gg and 69.0 Gg during the same period.

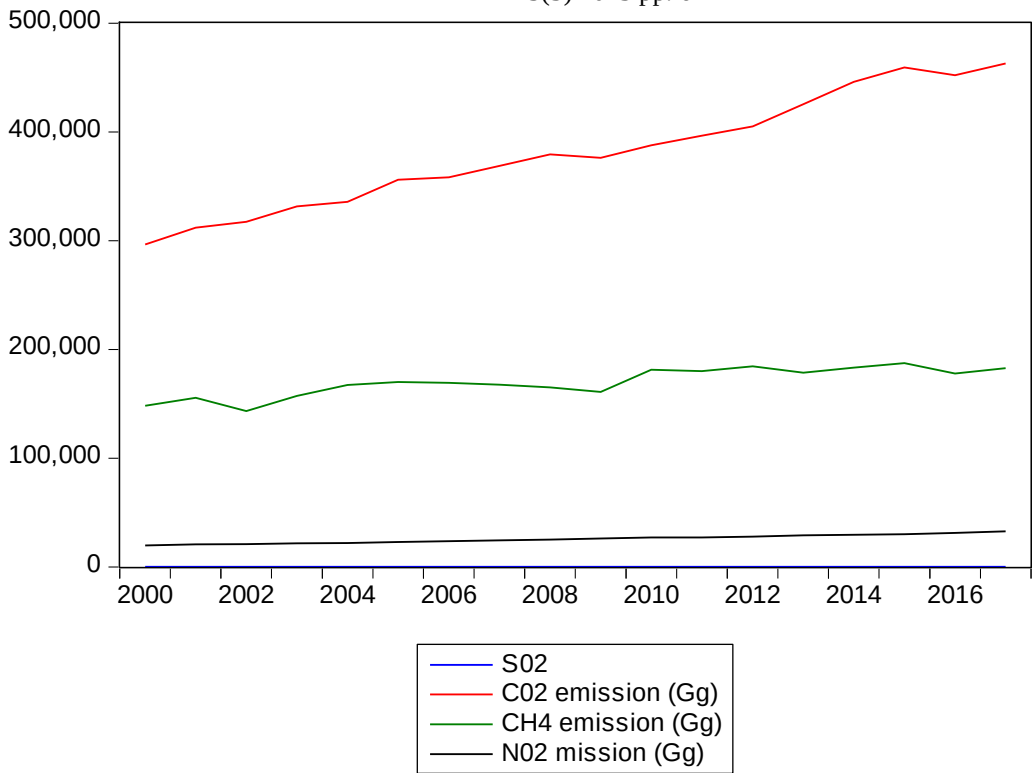

Figure 1: Trend analysis of aggregate Green House Gas emissions from 2000 to 2017

The trend analysis of aggregate gas emissions from 2000 to 2017 showed that S02, CO2, CH4 and $N0_2$ had a positive trend of persistent and continuous increase over the years under study. For instance, in the year 2002, 52Gg of gases was emitted, 143,306Gg of CH4, N02 was 20,906 while $C0_2$ was 317,288. Gg. While in the year 2010, values of $S0_2$ decreased to 50 while that of CH4, $N0_2$ and $C0_2$ increased to 181,339Gg, 27,124Gg and 387,708Gg respectively. These gases, especially SO2, are emitted by the burning of fossil fuels or other materials that contain sulfur. Sulfur dioxide can damage trees and plants, inhibit plant growth, and damage sensitive ecosystems and waterways. It also can contribute to respiratory illness and aggravate existing heart and lung conditions.

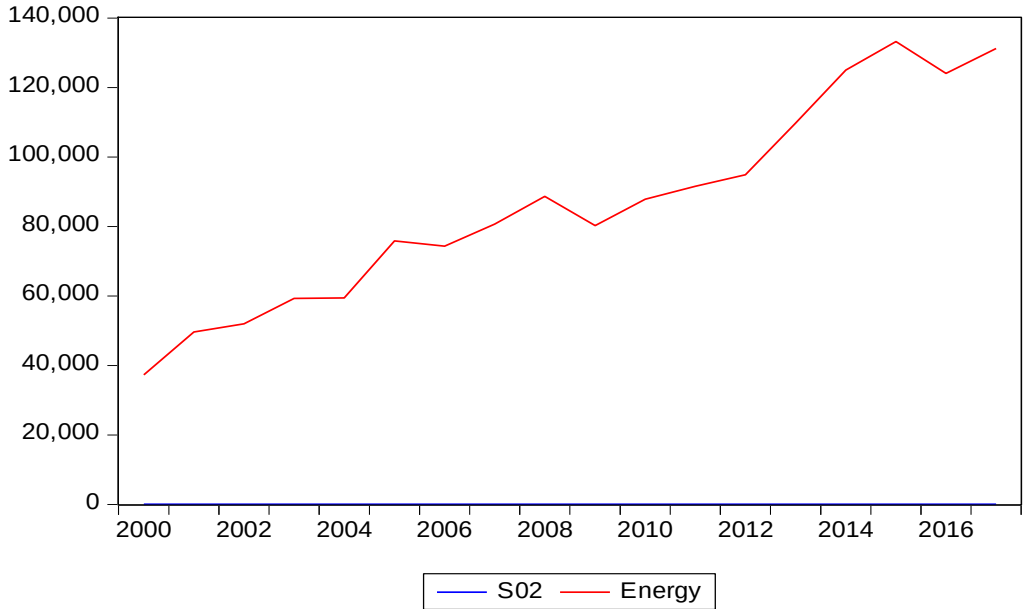

Figure 2: Effect of S02 gas emissions on energy performance in Nigeria from 2000 to 2017

In the modern economy, there is hardly increase in industrial productivity without intensive use of energy and this is said to generate more carbon emission in Nigeria like any other emerging and industrialized world. The trends in Fig. 3.4 showed that the level of percentage changes in energy consumption had a positive relationship $S0_2$ emission generated. This imply that as little as the energy consumption could be, higher rates of S02 are emitted constantly in Nigeria. Between 2000 and 2009 and between 2010 and 2017, the level of S02 emission and changes in energy were marginally at 41 tons and 37%, and 46 tons and 80,654% respectively.

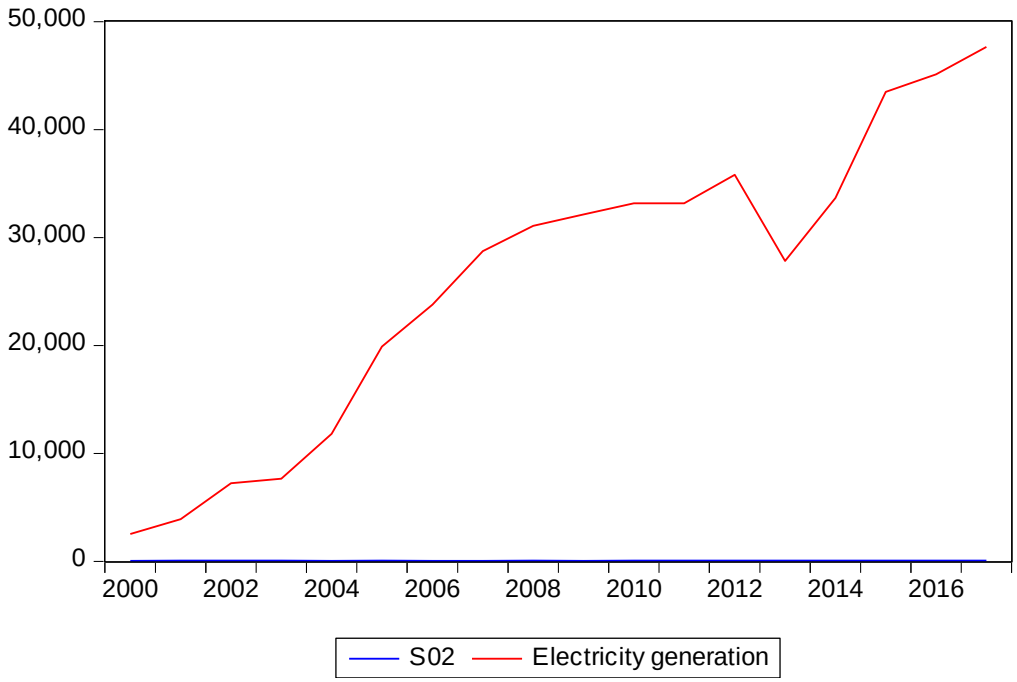

Figure 3. Effect of $S0_2$ gas emissions on electricity generation in Nigeria from 2000 to 2017

Public electricity and heat production is the most important source of CO_2 emissions (around one-third of all CO_2 emissions) and is the largest and second largest source respectively of SO2 and NOx emissions (the largest for the latter being transport). Coal, lignite and oil all naturally contain significant amounts of carbon, sulphur, nitrogen, which react with oxygen during combustion to form the oxides that cause damage to the environment. Natural gas contains significantly less of these chemicals, thus a switch from coal or lignite to natural gas leads to an environmental improvement. Emissions of SO_2 from public electricity and heat production has been on the increase over the years. As per CO_2 emissions, the emissions of SO2 had been on increase in line with the additional amount of electricity and heat produced.

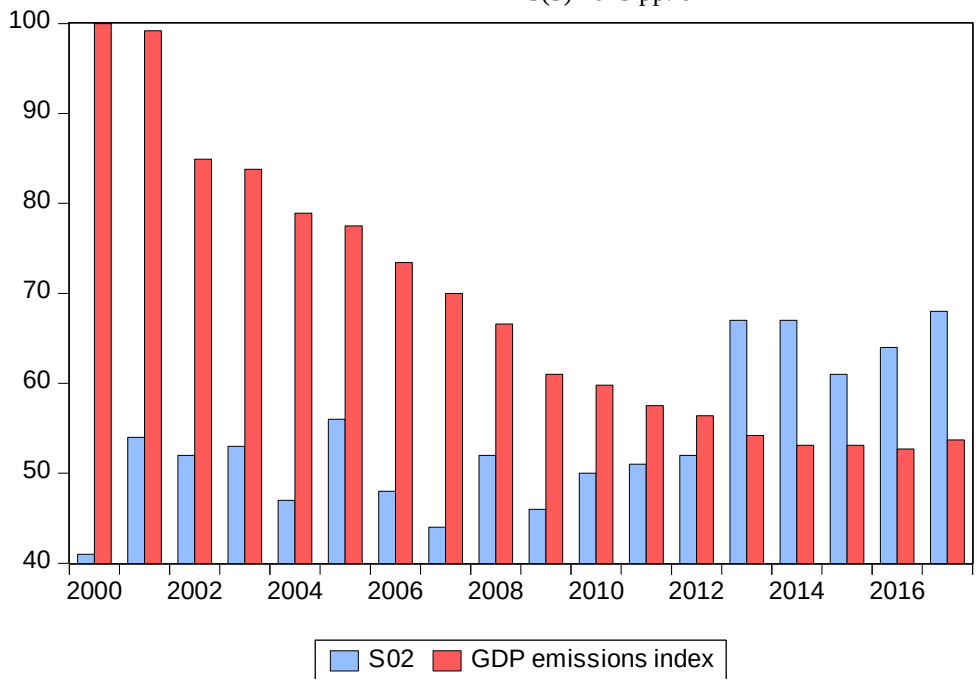

Figure 4: Trend analysis of S02 gas emissions against Gross Domestic Product emission index in Nigeria from 2000 to 2017.

The result of the study showed that an increase in level of GDP would initially increase S02 emission pollution. This SO_2 has a hazardous effect on human body. Short-term exposures to SO2 can harm the human respiratory system and make breathing difficult. People with asthma, particularly children, are sensitive to these effects of SO_2. SO_2 emissions that lead to high concentrations of SO2 in the air generally also lead to the formation of other sulfur oxides (SOx). SOx can react with other compounds in the atmosphere to form small particles. These particles contribute to particulate matter (PM) pollution. Small particles may penetrate deeply into the lungs and in sufficient quantity can contribute to health problems.

Table 2: Regression analysis of $S0_2$ against energy, Gross Domestic Product emission index, electricity generation and other aggregate gas emission

Dependent Variable: S02
Method: Least Squares
Date: 01/12/23 Time: 03:46
Sample: 2000 2017
Included observations: 18

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C02	0.000853	0.000425	2.007120	0.0699
CH4	1.19E-05	0.000121	0.097813	0.9238
EG	0.000889	0.000168	7.282965	0.0003
ENERGY	0.001426	0.000510	6.793365	0.0004
GDP_EI	-0.018517	0.159600	-5.116021	0.0003
N02	0.005395	0.001938	2.784065	0.0178
C	140.2683	77.99482	1.798431	0.0996

R-squared	0.925588	Mean dependent var	54.05556
Adjusted R-squared	0.885000	S.D. dependent var	8.199514
S.E. of regression	2.780586	Akaike info criterion	5.168501
Sum squared resid	85.04822	Schwarz criterion	5.514757
Log likelihood	-39.51651	Hannan-Quinn criter.	5.216245
F-statistic	22.80443	Durbin-Watson stat	1.737547
Prob(F-statistic)	0.000013		

Table 2 showed the regression of $S0_2$ against energy, Gross Domestic Product emission index, electricity generation and other aggregate gas emission.

The result of the study revealed that a unit increase in $S0_2$ emission will lead to 0.000853 unit increase in $C0_2$ emission. This relationship was a positive relationship. Unit increase in $S0_2$ emission led to 1.19E-05unit increase in CH_4. Similarly. The result revealed that a unit increase in $S0_2$ emission will lead to 0.005395unit increase in $N0_2$ emission.
Energy consumed had a significant positive relationship with $S0_2$ emission. The result of the study showed that a unit increase in S02 emission will lead to 0.001426 unit increase in Energy consumed. Finally, Gross Domestic product Emission index recorded a negative relationship with S02 emissions in the country.

4. Conclusion

With the knowledge that increases in greenhouse gases poses a threat to an economy, it is necessary for the government of Nigeria to work out formidable energy and environmental policies that will help in addressing the challenge of greenhouse gas emission. As part of the policy fallouts from the empirical findings of this study, Nigeria should be tenacious in meeting the requirement in the signed pacts of the Paris Agreement on greenhouse gas emission and her Nationally Determined Contributions (NDCs) to reduce GHG emission conditionally by 20% and conditionally by 45%. Also, the recommended SO_2 emissions of 50 mg/Nm^3 were exceeded. Emission increases were largely attributed to inefficient environmental impact assessment (EIA) licensing system, poor monitoring and auditing by EMA, as well as non-deterring SO_2 emission exceed penalties imposed on offenders. Communities located around smelters are adversely impacted by SO_2 emissions, with respiratory diseases the dominant symptom. Legally-binding emission standards developed and enforced through stringent license arrangements are proposed.

4.1 Recommendations

Therefore, to ensure increase in economic growth while maintaining environmental quality, government and the concerned agencies should consider the following policy recommendations:
a) In partnership with the Ministry of Finance, and the Ministry of Environment, the government of Nigeria should maintain expenditure on infrastructures that are environmentally friendly and encourage renewable energy investors through subsidies and incentives so that as the economy grows, the threat of climate change can be adapted and mitigated through reduction in emissions.
b) It was found that energy consumption and financial development negatively responded to carbon dioxide emissions in the long run, therefore, the Ministry of finance in partnership with the ministry of environment should strengthen efforts already signed in the first half of the year 2016 towards issuance of green bond. The policy tool of environmental tax should also be utilized immensely. In this case, taxing polluters for externality will in a way help to succor adverse effects of pollution or emission from industrialists.
d. Government should set up energy efficient measures that will improve energy use and promote access to renewable energy which is hoped to decrease emissions in the long run.
e) African led research is essential and currently insufficient to build climate resilient economy, therefore efforts should be geared by the Nigerian government to expand investment on Research and Development (R&D) to be able to discover alternative energy sources that will lead to capacity production while maintaining low level of carbon dioxide emissions.

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