American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-5, Issue-1, pp-62-72
www.ajer.org
Research Paper Open Access

Development of a Renewable Energy Integration Model for Carbon Regulation in a Developing Nigeria Grid

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ABSTRACT: *This paper carried out the development of a model for renewable energy integration as a solution to carbon regulation in the developing Nigeria power system. The integration of renewable energy resources into the power grid is driven largely by environmental regulation aimed at promoting sustainable energy resources and reducing carbon emission resulting from energy use. The Nigeria power system depends mainly on conventional sources for power generation. This obviously has increased the carbon emissions in Nigeria. This paper adopted a percentage by percentage renewable integration approach in an attempt to mitigate the rate of carbon emissions in the Nigeria electric power sector. This approach has been carried out for the various power stations operational as at 2010. Deductions and results show that as percentage of renewable integration increases, carbon emission reduces. As markedly observed, reduction in carbon emission occurs mostly for generating stations with large installed capacity. This is because the installed capacity was found to have a linear relationship with the amount of carbon emitted. Also, the relationship between the amount of renewable integrated and the reduction in carbon emissions has been represented by a linear equation. This is an invaluable tool in deductions involving renewable energy integration and carbon emission in the Nigerian power sector.*
Keywords *– Renewable energy integration, sustainable energy, carbon regulation, carbon cap, renewable portfolio standards, carbon emission.*

I. INTRODUCTION

The integration of renewable energy resources into the power grid is as a result of environmental regulation aimed at promoting sustainable energy resources and reducing carbon emission resulting from energy use. Price and quantity controls of carbon emissions through taxation and cap and trade policies, along with renewable portfolio standards (RPS) are the primary drivers for massive penetration of renewable energy resources and for electrification of transportation. Environmental regulations, aimed at reducing carbon emissions, are setting aggressive targets that will require high levels of renewable penetration. For instance, Assembly Bill 32 in California set goals of cutting back greenhouse gas emissions to 1990 levels by 2012 and the RPS mandates 33% integration of renewable energy in California by 2020[1]. As wind penetration increases the aforementioned challenges may impact system reliability, dispatch efficiency, cost of operation and may even undermine the environmental goals that RPSs, aim to achieve, unless the adverse impact of such penetration can be mitigated through technological innovation [2].

A non-renewable resource is a resource that does not renew itself at a sufficient rate for sustainable economic extraction in meaningful human time-frames [3]. An example is carbon-based, organically-derived fuel. The original organic material, with the aid of heat and pressure, becomes a fuel such as oil or gas. Fossil fuels (such as coal, petroleum, and natural gas), and certain aquifers are all non-renewable resources.

The objective of this paper is to reduce carbon emission by integrating renewable energy of different mix in the Nigerian grid network. This can be achieved by:
(i) Reducing carbon emission of other air pollutants through increased use of renewable energy and other clean distributed generation.
(ii) Establishing a relationship between renewable energy integration and reduction between CO_2 emissions.
This paper is limited to carbon emission quantification while the technical considerations like voltage and stability analysis of integration of renewable energy systems (RES) is beyond the scope of work.

Renewable technology sources include wind, hydro, solar, biomass, etc. Air flow can be used to run wind turbines. Modern utility wind turbines ranges from about 600kW to 5MW of rated power. The power available from the wind speed increases, power output increases dramatically up to the maximum output for the particular

turbine [4]. Areas where wind are stronger are more constant such as offshore and high altitude site, are preferred locations for wind farms. As offshore wind speeds average 90% greater than that of land, so offshore resources can contribute substantially more energy than land stationed turbines [5].
Energy in water can be harnessed and used for hydro power. Since water is about 800 times denser than air, even a slow flowing stream of water or moderate sea swell can yield considerable amount of energy [6].

Solar energy is the ultimate energy source driving the earth. Though only one billionth of the energy that leaves the sun actually reaches the earth's surface, this is more than enough to meet the world's energy requirements. In fact, all other sources of energy, renewable and non-renewable, are actually stored forms of solar energy. The process of directly converting solar energy to heat or electricity is considered a renewable energy source. Solar energy represents an essentially unlimited supply of energy as the sun will long outlast human civilization on earth. The difficulties lie in harnessing the energy. Solar energy has been used for centuries to heat homes and water, and modern technology (photovoltaic cells) has provided a way to produce electricity from sunlight. There are two basic forms of radiant solar energy use: passive and active. Solar power can be 120 thousand times the total electrical energy the country's utility companies produce for the nation in 2002 and at present. It also shows that the solar energy base of the country is good enough and worth investing on [6].

Biomass energy is the oldest energy source used by humans. Biomass is the organic matter that composes the tissues of plants and animals. Until the Industrial Revolution prompted a shift to fossil fuels in the mid-18th century, it was the world's dominant fuel source. Biomass can be burned for heating and cooking, and even generating electricity. The most common source of biomass energy is from the burning of wood, but energy can also be generated by burning animal manure, herbaceous plant material, peat, or converted biomass such as charcoal. Biomass can also be converted into a liquid biofuel such as ethanol or methanol. Currently, about 15 percent of the world's energy comes from biomass. Biomass is a potentially renewable energy source. Unfortunately, trees that are cut for firewood are frequently not replanted. In order to be used sustainably, one tree must be planted for every one cut down. Biomass is most frequently used as a fuel source in developing nations, but with the decline of fossil fuel availability and the increase in fossil fuel prices, biomass is increasingly being used as a fuel source in developed nations. One example of biomass energy in developed nations is the burning of municipal solid waste. In the United States, several plants have been constructed to burn urban biomass waste and use the energy to generate electricity. The use of biomass as a fuel source has serious environmental effects. When harvested trees are not replanted, soil erosion can occur. The loss of photosynthetic activity results in increased amounts of carbon dioxide in the atmosphere and can contribute to global warming. The burning of biomass also produces carbon dioxide and deprives the soil of nutrients it normally would have received from the decomposition of the organic matter. Burning releases particulate matter (such as ash) into the air which can cause respiratory health problems.

The effects of renewable energy sources include negative net energy which is one of the biggest effects of using alternative energy sources and troublesome fact that it often requires more fossil fuel inputs than the energy source yields, space and location issues like in solar power requiring large tracts of land in order to generate the kind of power necessary for large cities, let alone a whole nation, harmful effect on environment and wildlife like wind turbines killing birds as they rotate or tidal power buoys disrupting fish migration routes, and unsightly fixtures about complaints that the installation of wind turbines would sully the view of the ocean and the horizon [7].

This work is paramount at this time due to the rising effect of global warming. The power sector has been found to be a major emitter of greenhouse gases, especially CO_2. It is in this respect that this research work focuses on reduction in carbon emissions from the power grid. The reduction in carbon emission is made possible by renewable integration into the power grid since Nigeria has a large potential of renewables.
This study only considered the Nigerian energy sector with focus on the electricity supply industry. This work will take its reference from developed countries where elaborate work has been accomplished on carbon emission regulation. Finally, the study will be limited to the next sixteen years in order to fit existing development policies such as vision 20:20:20.

The primary disadvantage of the non-renewable energy resources is that they have a very negative effect on the environment from the mining, to the processing and consumption. Coal processing plant leach toxic metals into ground water and produce tons of additional waste, while gasoline burned in combustion engines emits carbon dioxide and other pollutants, contributing to global climate change. Natural gas is mainly methane, which is twenty times more effective at trapping heat than carbon dioxide, making it twenty times more problematic as a greenhouse gas [4].

Also, non-renewable energy resources pose problems to human health. For instance, uranium, which is used in nuclear power plants, causes birth defects and abnormal heart, liver, and kidney functions with prolonged exposure.
Because unsustainable energy reserves are limited, they will become more and more expensive as they are used. Consider the state of gas prices today, and imagine how these prices will continue to rise as oil becomes rare and gasoline is no longer an easily accessible resource.

Eventually, all non-renewable energy resources will be depleted; the name itself admits this inevitability. When this happens, all technologies still running on these fuels will become obsolete, and many people may suffer in their absence. We must turn to other forms of energy production; like wind, solar, and geothermal power sources, which can be used indefinitely. With these alternatives, the process of technology conversion should begin sooner rather than later. It would be better to stop deploying fossil fuels for power generation before they completely disappeared.

II. CARBON REGULATION

Carbon regulation derives from a realization of the effects of greenhouse gas (GHG) emissions (particularly CO_2 emissions). This has been termed "global warming". The effect of this has been seen in melting of ice of the ocean which has led to unusual flooding in parts of the world and unusual increase in temperature levels [8]. Moreover, cases of asthma, heart attacks, stroke and death have been reported due to inhalation of these gases. These pollutants have been observed to affect people who live in proximity to power plants but also those who live downwind, often hundreds and even thousands of miles from the plant's actual location [8]. Coal fired power plants in the United States release enough of these gases in the atmosphere each year to cause more than thirteen thousand premature deaths and hundreds of thousands of asthma attacks [9]. The aggregate toll caused by these harmful health impacts, and the resulting medical bills and lost wages can exceed $100 billion in one year [10]. Nigeria has not been spared its own trauma. It is estimated that 79,000 deaths occur annually as a result of smoke from traditional three stone-wood stoves [10].
With these revelations, it is important to unravel ways of curbing these emissions. Carbon regulation seeks to explore ways of curbing carbon emissions into the atmosphere by establishing carbon reduction measures. One of the ways to curb these emissions is by reducing the amount of non-renewable power generation and increasing renewable energy sources. Operators of power generating stations will be restricted on the amount of carbon to be emitted. Failure to comply will attract stringent financial obligation by the power company to account for amount of carbon emitted [10].
Acceptable standards of carbon regulation now exist globally. Emission standards are requirements that set specific limits to the amount of pollutants that can be released into the atmosphere [10]. Different countries of the world have laid down standards that are effective within their domain. All these standards lay credence to two major world agreements or treaties. They are the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto protocol.
The United Nations Framework on Climate Change (UNFCCC) is an international environmental treaty negotiated at the United Nations Conference on Environment and Development (UNCED), informally known as the Earth Summit, held in Rio de Janeiro, with the objective to stabilize greenhouse gas concentrations in the atmosphere [11]. It provided a framework for negotiating specific international treaties (called protocols) that may set binding limits on greenhouse gas [12].
The Kyoto protocol to the UNFCCC is an international treaty that sets binding obligations on industrialized countries to reduce emissions of greenhouse gases. They are those who have agreed to cap their GHG emissions at their base year levels. They are not obligated by caps that allows their emissions to expand above their base levels or countries that have not ratified the Kyoto protocol. For instance, the European Union as a whole has in accordance with the Kyoto protocol committed itself to an 8% reduction. Although not all member countries have complied, France has committed itself not to expand its emissions [13].

2.1 Carbon Regulation Experiences from Developed Countries

Carbon regulations in developed countries can be summarized as a lesson to developing countries. It is necessary to reveal carbon regulation standards in some developed countries such as China, Germany, UK, U.S.A, Canada, and Russia. The energy policy of China is a policy decided on by the Central Government with regard to energy and energy resources. The country is currently the world's largest emitter of greenhouse gases according to Dutch research energy [4]. However, China's per capita emissions are still far behind some of the developed countries. In 2011, the State Council released the Comprehensive Work Plan on Energy Conservation and Emission Reduction for a Five-Year Plan Period. China has therefore towed the path of carbon emission reduction by its conspicuous achievements in energy conservation, rapid development in non-fossil energy and strengthening energy conservation in industry.

The building sector is regarded as the key to greater energy efficiency in the German Energy Concept from 2010 [14]. In this field, the measures planned are the inclusion in the revised Energy Saving Ordinance of 2012 and the development of a renovation roadmap for existing buildings which starts in 2020 of the climate neutral building standard, to be met by new buildings by 2020.
Over the past 20 years, Russia has enacted complex and strict environmental legislation that in many cases meets or exceeds commonly accepted international standards. However, the enforcement of this legislation has been uneven [2]. Russia is continuing to develop its legislation and currently has new draft resolutions in the State Duma.
Although it ratified the Kyoto Protocol on climate change in late 2004, it has only recently enacted the legislation necessary to advance joint implementation projects and the trade of carbon credits. Carbon regulation has been carried out in the following ways - federal and regional legislation, environmental regulation, environmental permits, pay-to-pollute, etc.

III. METHODOLOGY

This paper focuses on mitigating carbon emissions from various generation stations in Nigeria through renewable energy integration. The major renewable energy resource used here is solar. This is because of its natural abundance in Nigeria. Solar is relatively mature for use in large capacities and so can have significant impact on the power grid that is likely to increase over time.

Standard emission rates have been used to obtain deductions of carbon emission rates due to each generating station. These standard emission rates have been sourced from [13]. Information from the standard rates was used to obtain the average emission rates (AER). The least value (R1) and the highest value (R2) of the AER have been summed up in a bid to obtain the average emission rate. Average emission rate for the most common conventional resources i.e. coal, natural gas and hydro have been deduced as sources of generation.

Also, AER for the target source (solar) has been obtained. This paper advocates a generation mix between the renewables and the conventional resources as a major way to curb carbon emission in our electric grid. Therefore, varying amount of renewables for integration has been considered. First, a 10% renewable integration for the various generation stations was considered. A 10% take-off is seen as ideal for meaningful achievements in a generation mix. This section continues to look at increasing amount of renewables integrated from a 10% take-off to a 20%, 30%, and 40% renewable integration respectively.

Also, the concept of a non-compliance cost was considered. This is the financial obligation for generation stations that do not comply with the renewable energy integration standard. The standard price for emitting carbon was obtained from [4]. This price has been put at €40 per ton of CO_2. This standard price will be adapted to obtain Non-Compliance Cost (NCC) for the various generation stations in Nigeria.

In addition to the AER, there is the need to obtain other parameters like the Carbon Emission Due to Installed Capacity, CEDIR (= Installed Capacity (kW) x AER), Carbon Emission Due to Generation Mix, CEDGM (= % Renewable Integration x Installed Capacity), Carbon Emission for Integrated Renewable, CEIR (= Cap(kW) x $AER_{Renewable}$), Carbon Emission for Remaining Output from Conventional Generator, CEROG (= Cap(kW) x $AER_{Non\text{-}Renewable}$).

3.1 Carbon Emission Rates

The average emission rate (AER) for the various generation resources are obtained as follows:

Coal: Emission rates for coal as a source of power generation is between 1.4pounds of CO_2 Emissions per kilowatt hour [CO_2E/kWh] and 3.6 pounds of CO_2E/kWh. Therefore, AER is obtained thus;

Average Emission Rate (AER) = (R1+R2)/2
AER (coal) = (1.4+3.6)/2
AER (coal) = 2.5pounds of CO_2E/kWh.

Natural Gas: Emission rate is between 0.6 pounds of CO_2E/kWh and 2pounds of CO_2E/kWh.
AER (Natural Gas) = (0.6+2)/2
AER (Natural Gas) = 1.3 pounds of CO_2E/kWh
Solar: Emission rate for solar is between 0.07 pounds of CO_2E/kWh and 0.2 pounds of CO_2E/kWh.
AER (Solar) = (0.07+0.2)/2
AER (Solar) = 0.135 pounds of CO_2E/kWh
Hydro: Emission rate is between 0.1 pounds of CO_2E/kWh and 0.5pounds of CO_2E/kWh

AER (Hydro) = (0.1+0.5)/2
AER (Hydro) = 0.3 pounds of CO_2E/kWh

3.2 The Power Stations and Their Deduced Emission Rates

The deduced emission rates of various power stations are obtained and presented as outlined here.

3.2.1 Generation Mix Due to 10% Renewable Integration

The 10% renewable integration into the power grid is presented as computed. Table I gives a picture of 10% generation mix with the integration of renewable energy across the power stations.

Table I: Showing a generation mix of 40% renewable energy integration to the various power stations

Power Stations	Installed Capacity (MW)	CEDIC (pounds of CO_2E/kWh) I.C×AER	CEIR (pounds of CO_2E/kWh) Cap(kw)×AER (Renewable)	CEROG (pounds of CO_2E/kWh) Cap(kw)×AER (Non Renewable)	CEDGM (pounds of CO_2E/kWh) CEIR+CEROG	NC (pounds of CO_2E/kWh)	NCC (€)
Kainji	760	760000×0.3 =228000	76000×0.135 =10260	684000×0.3 =205200	10269+205200 =215460	228000-215460 =12540	5.7×40 =228
Jebba	578.4	173520	7808.4	156168	163976.4	9543.6	173
Shiroro	600	180000	8100	162000	170100	9900	179.6
Afam	706.6	922480	9579.6	830232	839811.6	82668.4	1500
Okpai	480	624000	6480	561600	568080	55920	1014.6
Sapele	1020	1326000	13770	1193400	1207170	118830	2156
Ajeokuta	110	143000	1485	128700	130185	1215	232.5
AES	315	409500	4252.2	368550	372802.5	36697.5	665.8
Delta	912	1185600	12312	1067040	1079352	106248	1927.8
Geregu	414	528200	5589	484380	489969	48231	875
Omoku	150	195000	2025	175500	177525	17475	317
Omotosho	335	435500	4522.5	39195	391950	43550	790
Olorunsogo	335	435500	4522.5	39195	391950	43550	790
Egbin	1320	1716000	17820	1544400	1562220	153780	2790

3.2.2 Generation Mix Due to 20% Renewable Integration

Here we will obtain emission rates due to a 20% renewable integration. Table II is the calculation for 20% renewable energy integration.

Table II: Showing a generation mix of 20% renewable energy integration to the various power stations

Power Stations	Installed Capacity (MW)	CEDIC (pounds of CO_2E/kWh) I.C×AER	CEIR (pounds of CO_2E/kWh) Cap(kw)×AER (Renewable)	CEROG (pounds of CO_2E/kWh) Cap(kw)×AER (Non Renewable)	CEDGM (pounds of CO_2E/kWh) CEIR+CEROG	NC (pounds of CO_2E/kWh)	NCC (€)
Kainji	760	228000	20520	182400	202920	25080	455
Jebba	578.4	173520	115680	138816	154432.8	19087.2	346
Shiroro	600	180000	16200	144000	160200	19800	359
Afam	706.6	922480	19159.2	737984	757143.2	165336.8	3000
Okpai	480	624000	12960	499200	512160	111840	2029
Sapele	1020	1326000	27540	1060800	1088340	237660	4312
Ajeokuta	110	143000	2970	114400	117370	25630	465
AES	315	409500	8505	327600	336105	73395	1331.7
Delta	912	1185600	24624	948480	973104	212496	3855.5
Geregu	414	528200	11178	430560	441738	96462	1750
Omoku	150	195000	4050	156000	160050	34950	634
Omotosho	335	435500	9045	348400	357445	78055	1416
Olorunsogo	335	435500	9045	348400	357445	78055	1416
Egbin	1320	1716000	35640	1372800	1408440	307560	5580

3.2.3 Generation Mix Due To 30% Renewable Integration

Emission rate for a 30% renewable integration is tabulated in Table III.

Table III: Showing a generation mix of 30% renewable energy integration to the various power stations

Power Stations	Installed Capacity (MW)	CEDIC (pounds of CO_2E/kWh) I.C×AER	CEIR (pounds of CO_2E/kWh) Cap(kw)×AER (Renewable)	CEROG (pounds of CO_2E/kWh) Cap(kw)×AER (Non Renewable)	CEDGM (pounds of CO_2E/kWh) CEIR+CEROG	NC (pounds of CO_2E/kWh)	NCC (€)
Kainji	760	228000	30780	159600	190380	37620	683.6
Jebba	578.4	173520	23425.2	121464	144889.2	28630.8	519.5
Shiroro	600	180000	24300	126000	150300	29700	538.9
Afam	706.6	922480	28738.8	645736	674474.8	248005.2	4500
Okpai	480	624000	19440	436800	456240	167760	3043.8
Sapele	1020	1326000	41310	928200	960510	356490	6468
Ajeokuta	110	143000	4455	100100	104555	38445	697.5
AES	315	409500	12757.5	286650	299407.5	110092.5	1997.5
Delta	912	1185600	36936	829920	866856	318744	5793
Geregu	414	528200	16767	376740	393507	144693	2625
Omoku	150	195000	6075	136500	142575	52425	951
Omotosho	335	435500	13567.5	304850	318417.5	117082	2124
Olorunsogo	335	435500	13567.5	304850	318417.5	117082	2124
Egbin	1320	1716000	53460	1201200	1254660	461340	8370

3.2.4 Generation Mix Due to 40% Renewable Integration

Lastly, emission rates due to a 40% renewable integration is shown in Table IV.

Table IV: Showing a generation mix of 40% renewable energy integration to the various power stations

Power Stations	Installed Capacity (MW)	CEDIC (pounds of CO_2E/kWh) I.C×AER	CEIR (pounds of CO_2E/kWh) Cap(kw)×AER (Renewable)	CEROG (pounds of CO_2E/kWh) Cap(kw)×AER (Non Renewable)	CEDGM (pounds of CO_2E/kWh) CEIR+CEROG	NC (pounds of CO_2E/kWh)	NCC (€)
Kainji	760	228000	41040	136800	177840	50160	910
Jebba	578.4	173520	31233.6	104112	135345.6	38174.4	692.6
Shiroro	600	180000	32400	108000	140400	39600	718.5
Afam	706.6	922480	283840.4	553488	591806.4	330673.6	6000
Okpai	480	624000	25920	374400	313920	223680	4058
Sapele	1020	1326000	55080	795600	850680	475320	8624
Ajeokuta	110	143000	5940	85800	91740	51260	932
AES	315	409500	17010	245700	262710	146790	2663
Delta	912	1185600	49248	711360	760608	424992	7711
Geregu	414	528200	22356	322920	345276	192924	3500
Omoku	150	195000	8100	117000	125100	69900	1268
Omotosho	335	435500	18090	261300	279390	15610	2832
Olorunsogo	335	435500	18090	261300	279390	15610	2832
Egbin	1320	1716000	71280	1029600	1100880	615120	11160.6

The results obtained from these deductions for the emission rates of installed capacity of the conventional generators and emission rate due to a generation mix (i.e. 10%, 20%, 30%, and 40% renewable integration, respectively) between the renewable and the conventional sources will be analyzed. The results so obtained are that of the emission rates of the installed capacity of the conventional generators and emission rates due to a generation mix.

IV. RESULTS AND DISCUSSIONS

Having obtained carbon emission rates of the generation stations due to installed capacity and generation mix, the resulting effect is discussed. Chats, tables, and graphs have been employed to examine the outcome of various amount of renewable integration. The emission rate of the conventional generation stations due to their installed capacity (without a generation mix) is considered too. The outcome of having a generation mix between the renewables and the conventional resources is examined.

4.1 Generation Stations and Emission Rates (Without a Generation Mix)

The carbon emission rates of the various generating stations deduced Section II is shown in Figure 1. From Figure 1, it can be seen that the highest carbon emission rates is that due to the Egbin Gas Power Stations. This is followed by Sapele, Delta, and Afam Gas Power Stations, respectively. This order is consistent with the installed capacities of the stations. The highest emission rate comes from Egbin Power Station with an installed capacity of 1320MW, followed by Sapele Gas Power Station which has an installed capacity of 1020MW, Delta Gas Power Station with 912MW installed capacity, Afam Gas Power Station with an installed capacity of 709.6MW, etc. The Olorunsogo and Omotosho Gas Power plants are at par in terms of the carbon emission rate. This is because these stations have the same installed capacity and operate with the same kind of conventional source. Low emission rate have been observed to come from Kainji, Jebba, Shiroro etc. This is largely due to the fact that the AER for hydro as a source of power generation is much lower than that for natural gas. The other reason being that they have much lower installed capacity than their gas fired counterparts such as Sapele, Egbin and Afam Gas Stations, etc.

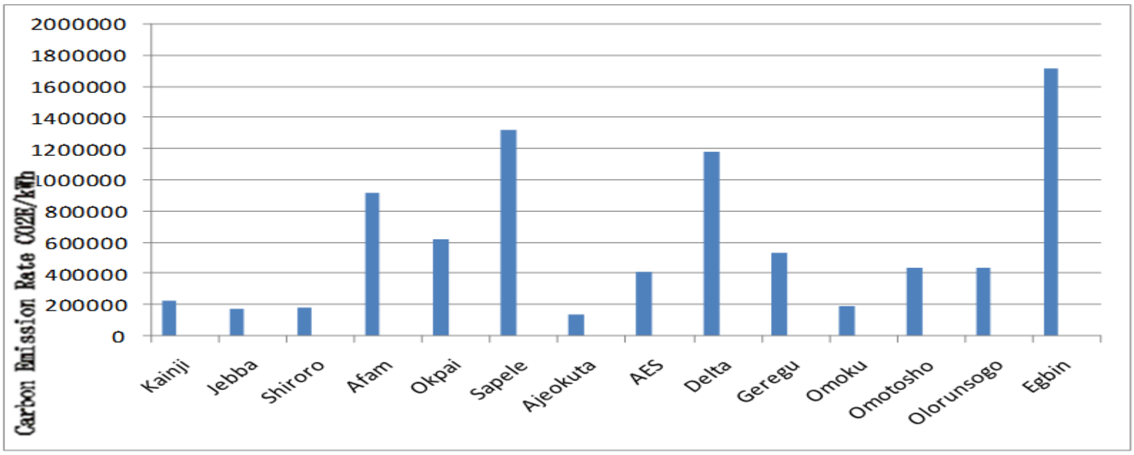

Figure 1: Chat showing the generating stations and their emission rates (without a generation mix)

4.2 Carbon Emission Due To a Generation Mix Of 10%, 20%, 30% and 40% Renewable

A chart depicting the effect of a10%, 20%, 30% and 40% renewable energy integration is shown in Figure 2.

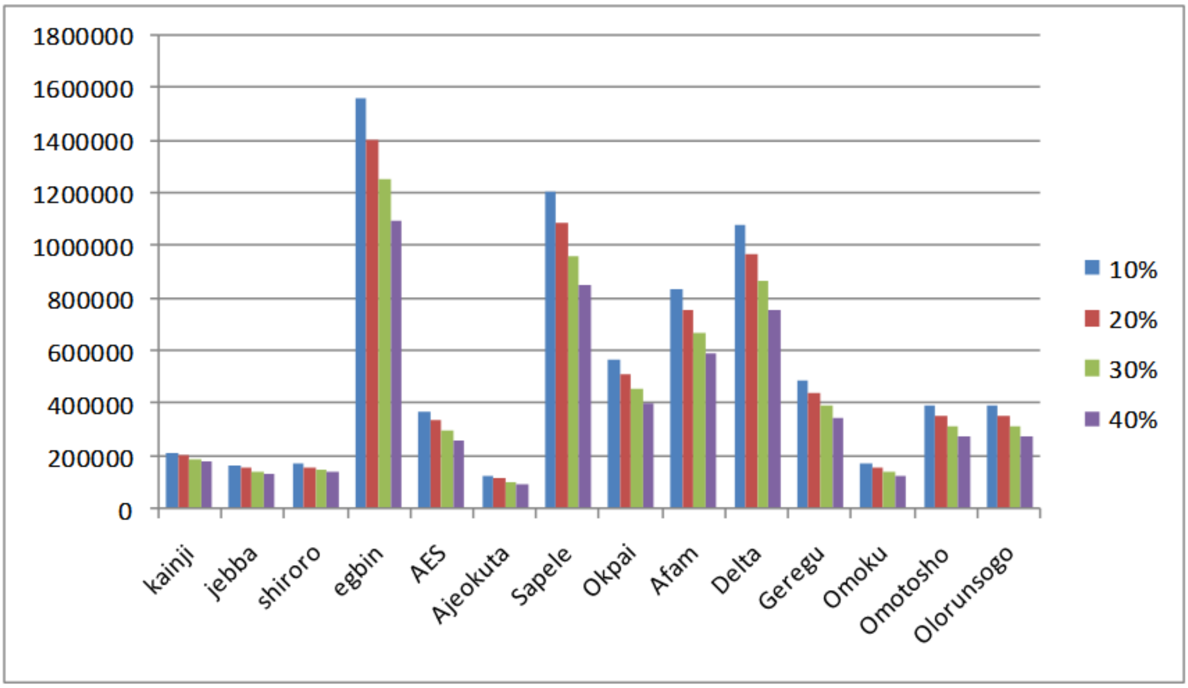

Figure 2: Chart showing the generation stations and the emission rate due to the generation mix of 10%, 20%, 30% and 40% renewable.

The minimum and the maximum reduction in carbon emission rate are obtained here for all power stations. A drastic reduction can be seen for Sapele Gas Power Station as emission rate fall from over 1,300,000pounds of CO_2E/kwh to about 850,000pounds of CO_2E/kwh. Large reductions are noticed for Okpai Gas Power station with a fall from over 600,000pounds to about 400,000pounds of CO_2E/kwh. Same goes for Ajaokuta Gas plant which achieved over 35% carbon emissions reduction. The effect of the renewable integration is further highlighted in Tables V – VIII for 10%, 20%, 30%, and 40% penetrations, respectively.

Table V: The percentage reduction in emission rate of power stations due to a generation mix of 10% renewable.

Power Stations	Carbon emission due to installed Capacity (CO_2E/kwh)	Carbon emission due to generation mix (CO_2E/kwh)	Percentage reduction (%)
Kainji	228000	215460	(228000-215460/228000)×100 =5.5
Jebba	173520	163976.4	5.5
Shiroro	180000	170100	5.5
Egbin	1716000	1562220	8.96
AES	409500	372802.5	8.96
Ajeokuta	143000	130185	8.96
Sapele	1326000	1207170	8.96
Okpai	624000	568080	8.96
Afam	922480	839811.6	8.96
Delta	1185600	1079352	8.96
Geregu	538200	489969	8.96
Omoku	195000	177525	8.96
Omotosho	435500	391950	10
Olorunsogo	435500	391950	10
Average percentage reduction=117.14/14=8.37%			

Table VI: The percentage reduction in emission rates of power stations due to a generation mix of 20% renewable.

Power Stations	Carbon emission due to installed Capacity (CO_2E/kwh)	Carbon emission due to generation mix (CO_2E/kwh)	Percentage reduction (%)
Kainji	228000	202920	11
Jebba	173520	154432.8	11
Shiroro	180000	160200	11
Egbin	1716000	1408440	17.92
AES	409500	336105	17.92
Ajeokuta	143000	117370	17.92
Sapele	1326000	1088340	17.92
Okpai	624000	512160	17.92
Afam	922480	757143.2	17.92
Delta	1185600	973104	17.92
Geregu	538200	441738	17.92
Omoku	195000	160050	17.92
Omotosho	435500	357445	17.92
Olorunsogo	435500	357445	17.92
Average percentage reduction=230.12/14=16.43%			

Table VII: The percentage reduction in emission rates of power stations due to a generation mix of 30% renewable.

Power Stations	Carbon emission due to installed Cap (CO_2E/kwh)	Carbon emission due to generation mix (CO_2E/kwh)	Percentage reduction (%)
Kainji	228000	190380	16.6

Jebba	173520	144889.2	16.5
Shiroro	180000	150300	16.5
Egbin	1716000	1254660	26.88
AES	409500	299407.5	26.88
Ajeokuta	143000	104555	26.88
Sapele	1326000	960510	26.88
Okpai	624000	456240	26.88
Afam	922480	674474.8	26.88
Delta	1185600	866856	26.88
Geregu	538200	393507	26.88
Omoku	195000	142575	26.88
Omotosho	435500	318417.5	26.88
Olorunsogo	435500	318417.5	26.88
Average percentage reduction=345.18/14=24.66%			

Table VIII: The percentage reduction in emission rate of power stations due to a generation mix of 40% renewable.

Power Stations	Carbon emission due to installed Cap (CO_2E/kwh)	Carbon emission due to generation mix (CO_2E/kwh)	Percentage reduction (%)
Kainji	228000	177840	22
Jebba	173520	135345.6	22
Shiroro	180000	140400	22
Egbin	1716000	1100880	35.85
AES	409500	262710	35.85
Ajeokuta	143000	91740	35.85
Sapele	1326000	850680	35.84
Okpai	624000	400320	35.85
Afam	922480	591806.4	35.85
Delta	1185600	760608	35.85
Geregu	538200	345276	35.85
Omoku	195000	125100	35.85
Omotosho	435500	279390	35.85
Olorunsogo	435500	279390	35.85
Average percentage reduction=460.35/14=32.88%			

The tables explicitly show the benefits of the various renewable integration to the grid. The average percentage reduction was evaluated accordingly.
With these results, it is obvious that renewable energy integration is a way out from the increasing carbonization of the Nigerian atmosphere due to generation of power.

4.2 Relationship between Penetration of Renewable Energy and Percentage Reduction of Carbon Emission

The graph of percentage penetration of renewables against percentage reduction in carbon emissions is presented. This is in a bid to establish the relationship between the two as shown in Table IX.

Table IX: Values for the percentage penetration of renewables and percentage reduction of carbon emission

Percentage Penetration	Percentage CO_2 Reduction
10%	8.37
20%	16.43
30%	24.66
40%	32.88

Figure 3 clearly shows a linear relationship between the percentage penetration of renewables and percentage reduction of carbon emission.

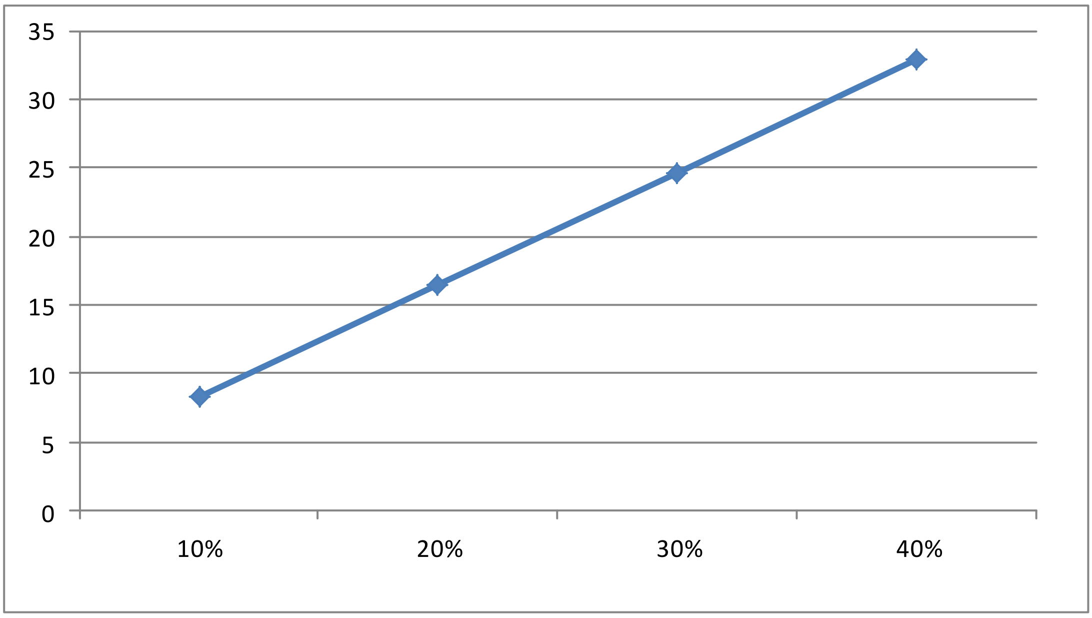

Figure 3: Graphical representation of the percentage penetration against the percentage reduction of carbon emission.

The graph so obtained shows a linear relationship between percentage penetration of renewables and percentage reduction of carbon emissions. The linear equation representing this relationship was obtained as

$$y=0.78x+0.5 \quad (1)$$

where y represents CO_2 reduction (%) and x, the renewable energy integration (%).
As the amount of renewable energy integrated is increased, so also the reduction in carbon emission. This equation is an invaluable tool in deductions involving renewable integration. It quickly tells how much carbon emission reduction can be achieved for a certain amount of renewable integration.
In order to adequately compensate for the pollution of the environment as a result of CO_2 emission, the NCC serves as a penalty for violation of carbon cap. Figure 4 shows the NCC for the power stations. Each power station will save the amount evaluated if it agrees to accomplish any of the corresponding level of integration as shown.

Table X: Showing the Non Compliance Cost (NCC) for all the power stations in each renewable integration.

Power Stations	NCC for each Percentage Renewable Integration (€)			
	10%	**20%**	**30%**	**40%**
Kainji	228	455	682.6	910
jebba	173	346	519.5	692.6
Shiroro	179.6	359	538.9	718.5
Afam	1500	3000	4500	6000
Okpai	1014.6	2029	3043.8	4058
Sapele	2156	4312	6468	8624
Ajeokuta	232.5	465	697.5	932
AES	665.8	1331.7	1997.5	2663
Delta	1927.8	3855.5	5793	7711
Geregu	875	1750	2625	3500
Omoku	317	634	951	1268
Omotosho	790	1416	2124	2832
Olorunsogo	790	1416	2124	2832
Egbin	2790	5580	8370	11160.6

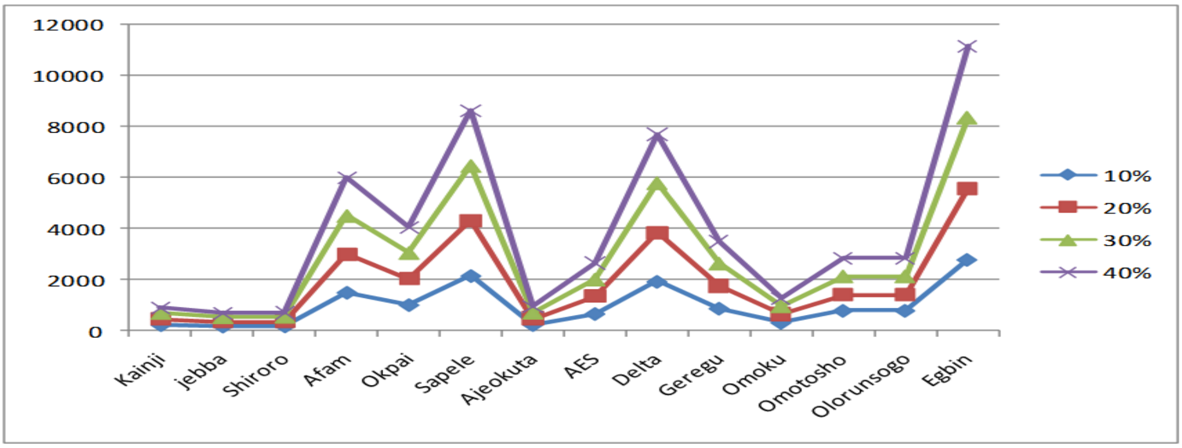

Figure 4: Graphical representation of the Non Compliance Cost (NCC) for the various renewable integration in all the power stations.

V. CONCLUSION

The quest to decarbonize our energy supply due to environmental concerns will result in massive deployment of renewable resources into the electricity supply infrastructure. The changes will normally create challenges due to the intermittent nature of renewable resources. This paper is premised on the proposition that an electric grid with carbon cap powered by mainly conventional generation resources is not sustainable and uneconomical in an environment with massive potential for renewable energy. Different penetrations of renewable energy have been proposed. A linear relationship between the percentage penetration of renewable energy and percentage reduction of CO_2 emission has been established. This model will be a handy tool for future evaluation of renewable energy penetration and government policies as it affects CO_2 emission from. Over the next years, the nation needs to make an intensive effort to deploy massive renewable technology for an effective power generation through renewables. This is supported by the non-compliance cost evaluated.

A business market has also been created due to the non-compliance cost in the event of non-compliance from power producers. Power producers will be on their toes to make sure that they do not violate the renewable integration standards. Otherwise, costs of carbon emitted will add to their operating cost.

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