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Challenges of Climate Changes as Opportunities for Renewable Energy Growth: A Global Perspective

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Abstract

The increasing anthropogenic emissions of carbon dioxide and other greenhouse gases since the beginning of the industrial revolution have caused global warming and climate change. The resultant extreme weather events constitute threats to human lives and have damaging impacts on the environment. Greenhouse gas emission reduction aimed at limiting global warming to $1.5^{O}C$ above pre-industrial level is a key strategy for climate change mitigation measure all over the world. This goal is being pursued using renewable energy resources in place of fossil fuels. The share of renewable energy in primary energy consumption increased from 6.3% in 1970 to 13.5% in 2021. Projections by both the International Renewable Energy Agency (IRENA) and International Energy Agency (IEA) indicate that the percentage contribution of renewables to global energy mix would continue to increase in the coming years. This implies that climate change mitigation creates growing opportunities for renewable energy research and development. Climate change is also a challenge for renewable energy resources. The performance of hydro-, solar and wind energy systems depend on weather parameters, and these parameters are affected by climate change. Furthermore, renewable energy installations are physical systems and therefore susceptible to the negative impacts of extreme weather events. Therefore, even though climate change is a challenge to mankind, it also presents opportunities for research, development and growth of renewable energy.

1.0 Introduction

Climate Change is a contemporary challenge for the global human society. All over the world, the frequency and intensity of extreme weather events such as floods, drought, heatwave, storms, have been increasing. These phenomena are manifestations of climate change that is driven by global warming. Global warming is attributed largely to human activities, especially the production and combustion of fossil fuels, that emit greenhouse gases into the atmosphere. In its series of climate change Assessment Reports (AR) issued since 1990, the IPCC has consistently stated that human activities are responsible for global warming and climate change. In the Sixth Assessment Report, the IPCC asserted that it is unequivocal that human influence has warmed the atmosphere, ocean and land, and that widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred. IPCC, 2021a. All economic sectors, including energy, are affected by these extreme weather phenomena. Renewable energy resources depend on weather parameters such as solar radiation, wind speed, rainfall, temperature. Acuzar *et al*., 2017; Orlov *et al*., 2020. Research results show that weather parameters have significant impacts on the performance of solar PV, solar thermal, hydro- and wind energy systems. (e.g., Anuforom *et al.,* (1987); Okeke & Anuforom (1987); Anuforom *et al*., (1989), Okeke & Anuforom, (1990); Sawadogo *et al*., 2020.; Egarievwe *et al*., (1991; Adio *et al*., (2021). These weather parameters have become more variable and less predictable due to climate change. The variabilities also affect the performance of renewable energy systems. The susceptibility of some renewable energy resources to future climate change has been reviewed by Gernaat *et al*., 2021, while Solaun & Cerdá, 2019, reviewed various studies on the quantitative estimates of climate change impacts on solar, wind, hydro and other renewable generation technologies. Feron, *et al*. (2020) concluded that climate change may affect renewable power outputs from PV systems by enhancing variability and making extreme temperature and cloudy conditions more frequent.

The high variability of the weather parameters due to climate change implies that the energy output from the renewable energy systems could be intermittent. This is a challenge for renewable energy resources. Like other physical infrastructure, renewable energy installations are susceptible to damage by extreme weather events. Therefore, even though renewable energy resources are increasingly being used for climate change mitigation, they are also affected by climate change.

2.0 Fossil Fuels Consumption and Anthropogenic Greenhouse Gas Emissions

The emission and buildup of anthropogenic carbon dioxide and other greenhouse gases (GHG) in the atmosphere started in the mid-18th century (circa 1750) with the First Energy transition that was occasioned by the Industrial Revolution in Britain. The shift from manual to mechanized system of production during the Industrial Revolution necessitated the First Energy Transition which was a shift from the use of biomass (wood, dry grass, charcoal) to coal (fossil fuel) as source of energy. With the growth in factory production, the invention of steam and internal combustion engines, the use of coal and other fossil fuels primary energy sources continued to grow as shown in Figure 1. Oil (petroleum) and natural gas became part of the global energy mix in the 20th century. The global total primary energy consumption increased from 5,653 terawatt-hour (TWh) in 1800 to 176,431 terawatt-hour (TWh) in 2021, out of which fossil fuels (coal, oil and gas) contributed 136,018 TWh (or 78%).

Fossil fuels are hydrocarbons, and their extraction, processing and combustion for energy generation result in the emission of carbon dioxide and other greenhouse gases (GHGs) into the atmosphere. The rates of emission and atmospheric concentrations of carbon dioxide (CO_2), methane (NH_4) and nitrous oxide (N_2O) from human activities have been increasing since the Industrial Revolution. This is attributable to ever-increasing global economic activities, coupled with growing human population.

Carbon dioxide emissions from fossil fuel combustion and industrial processes such as

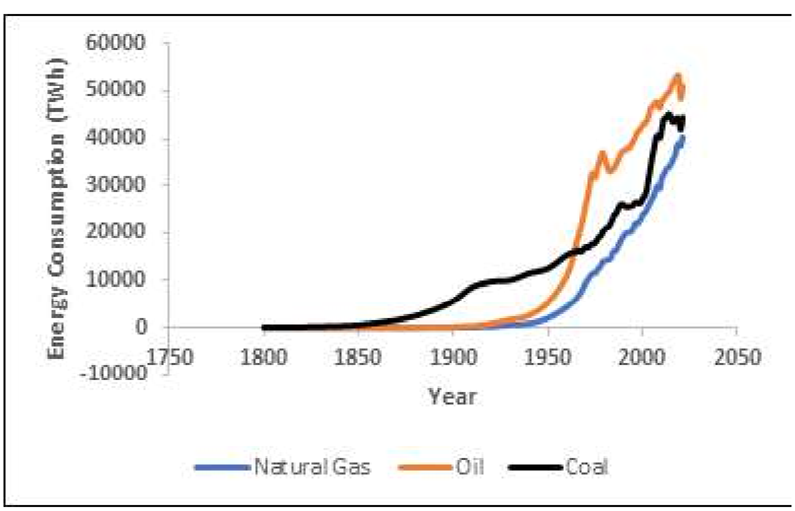

Figure 1: Primary Energy Sources since the First Industrial Revolution
[*Source of data:* Ritchie *et al*. (2022a)]

cement and steel production, increased from 9.351 metric tons in 1751 (onset of Industrial Revolution) to 37,124 million metric tons in 2021. Ritchie, *et al*., 2020a. (See Figure 2). The annual energy-related CO_2 emissions further increased to 36,800 million metric tons in 2022. As of March 2021, the atmospheric concentration of CO_2 was 149%, while methane and nitrous oxide concentrations were 262% and 124% higher than the pre-Industrial levels. WMO, 2022.

The concentrations of the other two main greenhouse gases, methane (CH_4) and nitrous oxide (N_2O) in the atmosphere, have also been increasing since the onset of the Industrial Revolution. According to the IPCC, as of 2019, the concentrations of methane and nitrous oxide in the atmosphere had reached 1866 ppb and 332 ppb, respectively, and these increases are *"unequivocally due to human activities"*. IPCC, 2021. As of 2020, the concentrations of these two GHGs in the atmosphere were 262% and 123% respectively, higher than their pre-industrial levels. WMO, 2021.

While the combustion of fossil fuels in the energy sector is the main source of carbon dioxide, methane is emitted mainly from activities in agriculture (especially livestock and wetland rice cultivation). The United Nations Environment Program (UNEP) estimated that activities in this sector contribute 40% of global methane emission, 35% comes from extraction and distribution of fossil fuels (oil, gas and coal), while 20% of the global methane emission come from waste (landfills, wastewater, decomposing organic materials). UNEP, 2021. With the growing human population worldwide, the emission of methane from these human activities have continued to increase. UNEP (2021) reported that over the past decade the amounts of methane increased rapidly and reached unprecedented five-year average growth rates in the 1980s.

3.0 Global warming and weather-related natural disasters

The observed increasing temperature of the Earth is the resultant effect of the heat-trapping property of the anthropogenic greenhouse gases that have been accumulating in the atmosphere since the Industrial Revolution.

Figure 3 shows the result of the analyses of six different global temperature datasets reported by the UK Met Office. All the datasets reveal that in addition to the periodic variabilities in global temperature, there is an obvious overall increasing trend since the beginning of the Industrial Revolution (similar to the trend in

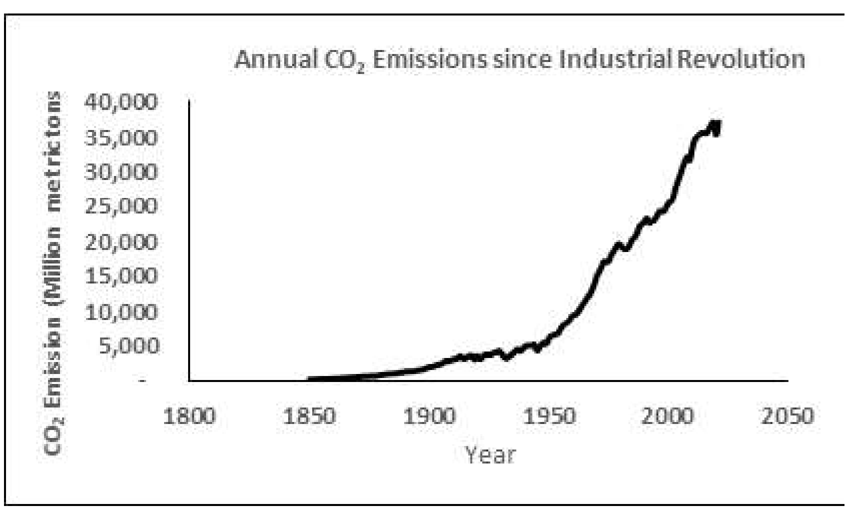

Figure 2: Global Carbon Dioxide Emission from 1750 to 2021
[*Source of data:* Our World in Data. Retrieved from: https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions. [(Online Resource)].

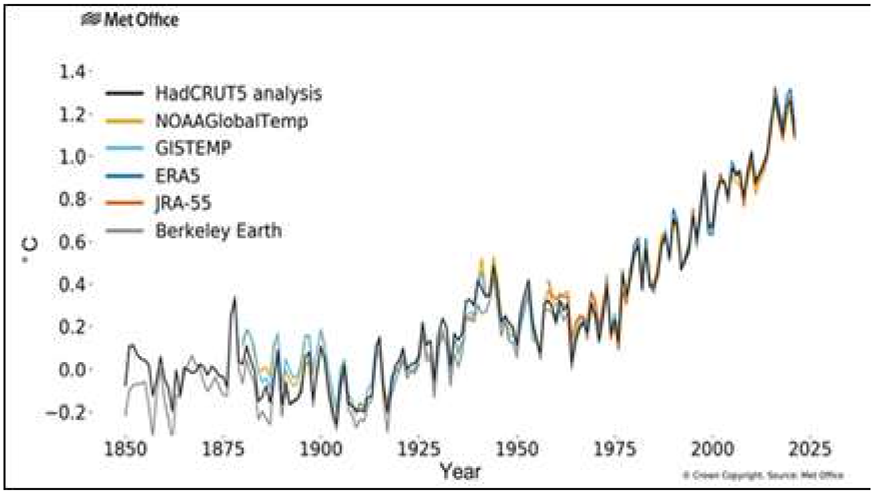

Figure 3: Global mean temperature difference from 1850 – 1900 average (°C)
(*Source*: WMO, 2022: *State of the Global Climate 2022. WMO-No. 1290)*

GHG emission). The World Meteorological Organization (WMO) reported that by 2020, global mean temperature increase had reached 1.2 ± 0.1°C above the 1850 - 1900 baseline (WMO, 2021). 2020 was noted as one of the three warmest years on record. The other two years were 2016 and 2019. Figure 4 shows that since the 1980s, global mean temperature in each successive year has remained higher than the 30-year (1961-1990 baseline) average. The recent seven-year period, 2015 to 2021, were the seven warmest years on record (WMO, 2022).

The observed changes in the climate system such as more frequent and intense extreme weather (like ferocious storms), heatwave, rising sea levels, melting glaciers, etc., are due to global warming. The energy that drives these processes come from the thermal radiation that is trapped in the lower atmosphere by anthropogenic greenhouse gases. The frequency of occurrence of these phenomena have been increasing rapidly, especially since the middle of the 20th century (see Figure 5).

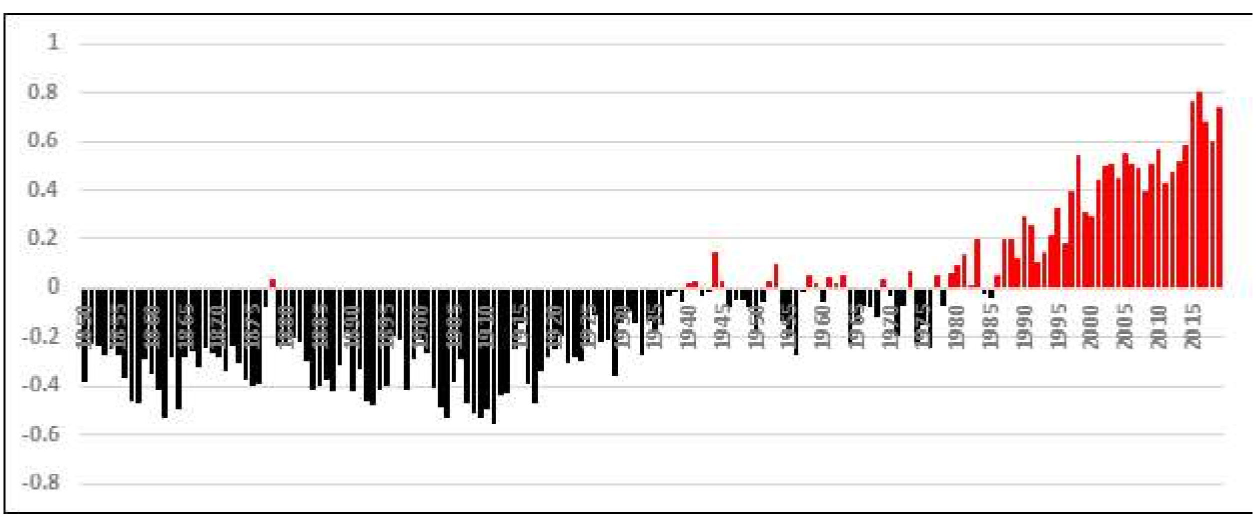

Figure 4: Global temperature anomaly from 1961-1990 average since 1850
(Source of data: Met Office Hadley Centre (Online resource) retrieved from https://ourworldindata.org/grapher/temperature-anomaly)

The analysis of the global extreme weather data of Ritche, *et al*. shows that in the first 50 years of the 20th century (i.e., 1900 to 1949) the average number of such events per year was 3.4 per year. Over the next 50 years (1950 to 2000) the frequency of occurrence increased to 46 per year. More recently between 2001 and 2020, a twenty-year period, the frequency increased further to an average of 104 extreme events per year. It was also reported by the World Meteorological Organization that in the 50-year period from 1970 to 2019, there were 11,072 reported weather-related disasters (i.e., an average of 221 disasters per year). WMO (2021). The frequency of extreme weather events and weather-related disasters have therefore been increasing at higher rates in recent years. These disasters have also resulted in deaths, injuries and extensive economic losses. The economic losses due to weather related disasters from 1970 to 2019 was estimated at US$ 3.64 trillion while 2.06 million lives were lost.

4.0 Projected Global Warming and Climate Change Challenges

Anthropogenic greenhouse gases have atmospheric lifetimes ranging from a few years to hundreds of years. Carbon dioxide does not have a fixed atmospheric lifetime. Its lifetime varies from 5 to 200 years, depending on the removal processes from the atmosphere. IPCC (2001). The atmospheric lifetimes of methane and carbon nitrous oxide are 12 and 114 years, respectively. This implies that once they are emitted into the atmosphere, their warming effects and extreme weather events are likely to persist for years to come. According to the IPCC, the scale of the negative impacts of these gases may even increase if steps are not taken to arrest the increasing concentration and the warming trend. Some studies, (e.g., Solomon, *et al*., 2009; Solomon *et al*., 2010), have demonstrated that the climate change effect of carbon dioxide may remain irreversible for hundreds of years once it has is emitted into the atmosphere. The IPCC also projects that warming of the global atmosphere due to anthropogenic emissions will persist for centuries to millennia and will continue to cause further long-term changes in the climate system. IPCC, 2022.

Rijsberman & Swart (1990) identified the need to limit global warming in order to avoid global scale climate change catastrophes. According to the authors, a 1°C increase in temperature of the Earth above pre-industrial level may trigger rapid, unpredictable and non-linear responses that could lead to extensive ecosystem damage. They further warned that 2°C above the pre-industrial levels is the upper limit of global

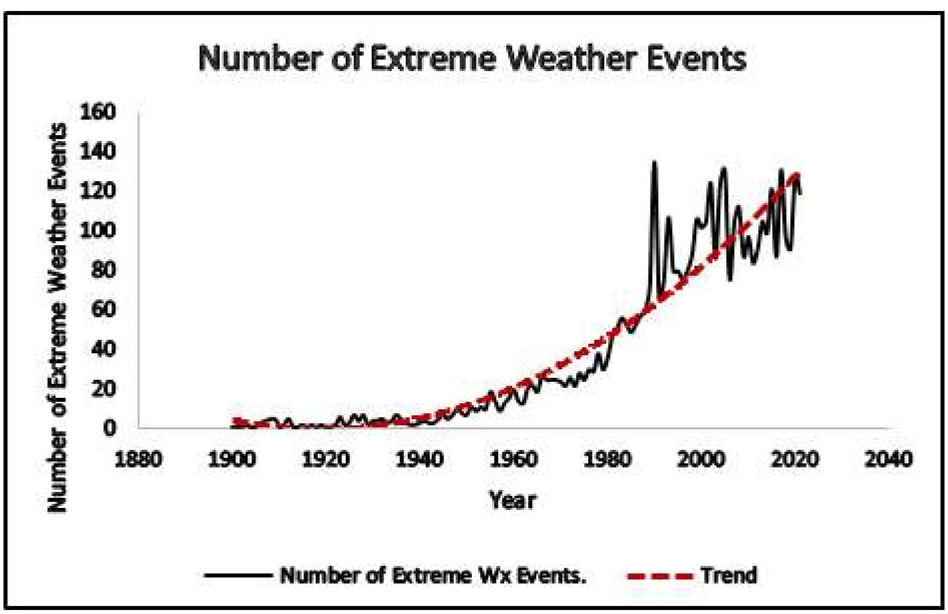

Figure 5: Extreme Weather Events (1900 to 2022)
Source of data: Ritchie, *et al.* (2022 b)

temperature increase beyond which the risk of grave and irreversible damage to the ecosystem increases rapidly. The IPCC also stated that, *"Climate-related risks to health, livelihoods, food security, water supply, human security, and economic growth are projected to increase with global warming of 1.5°C and increase further with 2°C."* IPCC (2018). Averting these changes and their catastrophic impacts is one of the greatest challenges of the contemporary global community. The Paris Climate Change Agreement was signed in 2015 as the response to this potential risk by countries of the world under the auspices of the United Nations Framework Convention on Climate Change (UNFCCC) secretariat. The goal of the Paris Agreement is to hold the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels. UNFCCC, 2015. This is to be achieved by reducing anthropogenic emission of CO_2 and other greenhouse gases.

5.0 Carbon Budget

Anthropogenic CO_2 has been accumulating in the atmosphere since the onset of the industrial revolution. This is because the rate of emission exceeds the rate of removal by natural carbon sinks. From 1750 to 2021 the estimated cumulative anthropogenic CO_2 emission from fossil fuels and industrial processes was 1.74 trillion tonnes It has now been well-established that there is a strong, consistent, almost linear relationship between cumulative CO_2 emissions and projected global temperature change upto the year 2100. IPCC, 2014; IPCC, 2021a. This implies that additional CO_2 emissions increase the global surface temperature almost linearly. This linear relationship allows the concept of Carbon Budget to be applied in determining the amount of additional anthropogenic CO_2 that could still be emitted over a given time period without exceeding the Paris Agreement target. Total Carbon Budget (TCB) refers to the maximum amount of cumulative anthropogenic CO_2 emissions that would result in limiting global warming to a given level with a given probability, taking into account the effect of other anthropogenic climate forcers since the industrial revolution. Closely related to this is the concept of Remaining Carbon Budget (RCB) which indicates how much CO_2 could still be emitted while keeping warming below a specific temperature level. IPCC, 2021b. Since the combustion of fossil fuels is still ongoing, the Remaining Carbon Budget decreases progressively with time. In 2016 when the Paris Agreement came into force, the Remaining Carbon Budget for a 33% likelihood of limiting global warming to 1.5^{O}C was 473 Gigatons CO_2 for fossil fuels. Kühne (2016). Every additional emission into the atmosphere reduces the carbon budget and increases global temperature. As of the beginning of 2023, the Remaining Carbon Budget for a 50 % likelihood to limit global warming to 1.5, 1.7, and 2^{O}C has, respectively, reduced to 380 $GtCO_2$, 730 $GtCO_2$, and 1,230 $GtCO_2$. Fredlingstein *et al.* (2022). These are equivalent to 9, 18, and 30 years, based on 2022 emissions levels. Limiting human-induced global warming to 1.5^{O}C therefore requires that net anthropogenic CO_2 emissions be reduced rapidly, so as to reach net zero globally by 2050. Net zero emission is achieved when anthropogenic emissions of greenhouse gases to the atmosphere are balanced by anthropogenic removals over the same period.

Since 2018 when the IPCC published its *Special Report on Global Warming of 1.5^{O}C*, drawing greater attention to the negative consequences of failure to limit global warming, many countries, including Nigeria, set their target dates (mostly from 2030 to 2060) for achieving net zero emissions. IPCC, 2018; IPCC 2021b. Considering the predominance of the energy sector as the source of anthropogenic greenhouse gases, a drastic change in how energy is produced and consumed by human societies is required for net zero emission to be achieved. This entails decarbonization of the energy sector by transition from fossil fuels to clean energy sources, among other measures. According to Orlov *et al.* (2020) ambitious mitigation policies aiming to align with a 1.5 °C global warming target require a radical increase in supplies of clean energy.

6.0 Energy Transition Plans – Opportunity for Renewables Energy Development

Energy transition is a shift from one type of primary energy source to another. The first energy transition that came in the 18th century with the industrial revolution was a shift from biomass to coal (a fossil fuel) as the primary energy source for economic activities and domestic use. Subsequently, the other fossil fuels, oil and gas, were added to the primary energy mix to meet the growing demand for energy and in response to advancement in technology. (See Figure 1). The energy sector has therefore remained the dominant source of anthropogenic carbon dioxide and other greenhouse gas emissions. Ritchie *et al*. (2020) estimated that about 73% of global CO_2 emissions come from the energy sector (electricity, heating and transport).

Driven by the need to reduce GHG emission, the consumption of renewable energy has been increasing since the past few decades. ***Obobisa (2022)*** demonstrated empirically that renewable energy consumption reduces CO_2 emissions, while fossil fuel energy consumption increases CO_2 emissions across regions and at the global level. Increasing the percentage contribution of renewable energy sources while reducing fossil fuel consumption has been receiving global attention (Figure 6).

Between 2010 and 2021, power generation capacity using renewables quadrupled worldwide from 754 GW to 3,064 GW. The growth was driven predominantly by solar PV systems which recorded a 21-fold increase during the period. IRENA, 2022a. Renewable energy, especially solar PV, has therefore gained prominence as a viable option for implementing carbon emission reduction worldwide. As of 2022, renewable energy sources contributed 14.21% of global primary energy consumption globally. Ritchie *et al*., 2022a. Further increase in renewable energy share of energy consumption is still necessary to achieve rapid and deep reductions in energy system CO_2 and GHG emissions. IPCC, 2022. Many countries around the world, including Nigeria, now have Energy Transition Plans (ETP) as part of the strategy to meet their Nationally Determined Contributions (NDC) commitment to Paris Agreement emission reduction targets, as well as achieve net zero emission by 2055. According to the World Economic Forum (WEF), 115 countries in the world (including Nigeria), had initiated their Energy Transition Plans as of 2020. WEF, 2021. As part of the country's ETP, Nigeria is aiming to achieve 179 $MtCO_2e$ emission reduction across the five energy subsectors. These are (i) Power (48 $MtCO_2e$); (ii) Transport (43 $MtCO_2e$); (iii) Cooking (40 $MtCO_2e$) (iv) Industry (29 $MtCO_2e$), and (v) Oil & Gas (19 $MtCO_2e$). These represent

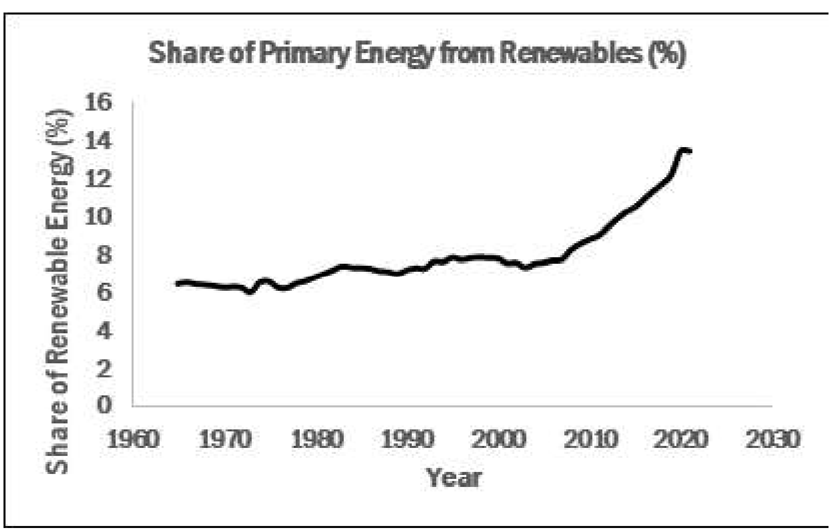

Figure 6: Share of Primary Energy Consumption Since 1965
Source of data: Ritchie *et al*., 2022a

27%, 24%, 22%, 16% and 11%, respectively, of Nigeria's energy sector GHG emissions.

Even though there are various climate change mitigation options (Xua & Ramanathan, 2017; Fawzy *et al*., 2020), the IPCC advises that a broad-based approach to deploying energy-sector mitigation options can reduce emissions in the near-term and set the stage for still deeper reductions beyond 2030. IPCC, 2022. The International Renewable Energy Agency (IRENA) estimates that using renewable energy, energy efficiency and other non-fossil fuel technologies could result in a cut of 36.9 gigatonnes of annual CO_2 emissions by 2050. IRENA, 2022. IRENA projected that renewable energy would directly contribute at least 25% of this amount emission cut. (Figure 7). Renewable energy based CO_2 removals would contribute 14% of the 36.9 gigatonnes of annual CO_2 emission.

The 'Roadmap to 1.5^{O}C by 5050' proposed by the International Renewable Energy Agency (IRENA) projects that by 2050, electrification with renewables would have increased to 90%, with a total addition of 1,528 GW/year from renewable technologies, solar PV and wind energy. The Agency also forecast that the share of renewables in final energy consumption would have increased to 79% by that year. IRENA, 2022.

The International Energy Agency (IEA) renewable energy forecasts, projects that between 2021 and 2026 an annual average addition of 305 GW of renewable electricity capacity is expected globally. The forecast anticipates that the growth, which will be driven mainly by PV, will accelerate over the coming years and account for about 95% of the increase in global power capacity from 2021 through 2026. During the period sub-Saharan Africa is expected to record an increase of 76% (i.e., about 33 GW) in renewable energy capacity. IEA, 2021. These forecasts show that even though climate change is a huge global challenge, it has also brought opportunities for development and increased uptake of renewable energy.

7.0 Conclusion

The emission and accumulation of anthropogenic greenhouse gases in the atmosphere has been going on since the beginning of the Industrial Revolution in the 18th century. As of 2021, the concentrations of carbon dioxide, methane and nitrous oxide in the global atmosphere due to human activities had reached 149%, 262% and 124%, respectively higher than the pre-Industrial levels. Global warming due to increasing concentrations of these gases had increased to 1.15 ± 0.13 °C above the 1850-1900 average, as of 2022. (WMO, 2022). The frequency and intensity of extreme weather events have also been increasing in step with global warming trend. According to the World Meteorological Organization (WMO), there were 11,072 reported weather-related disasters from 1970 to

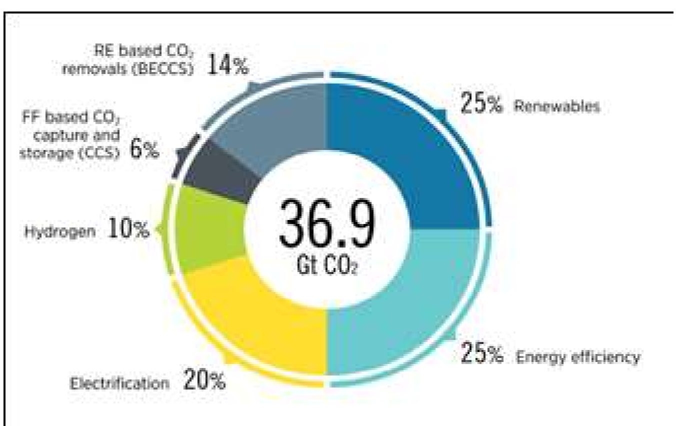

Figure 7: Technologies for achieving 36.9 Gt CO_2 emission reduction by 2050
Source: IRENA, 2022

2019. The estimated economic losses caused by these extreme weather events were \$3.64. In addition, 2.06 million lives were lost due to the weather disasters during the period.

The IPCC projections show that the disastrous impacts of climate change would likely continue and probably increase in the coming decades and that the damage to the climate system could become irreversible if global warming exceeds 2^{O}C above the pre-industrial level. The goal of the Paris Agreement is to keep the global limit the global temperature increase to 1.5^{O}C above pre-industrial levels by reducing the human-caused emissions of CO_2 and other greenhouse gases.

Countries around the world are now aiming at achieving Net Zero Emission by 2050. This target is being pursued with Energy Transition Plans. Using renewable energy, energy efficiency and other non-fossil fuel technologies could result in a cut of 36.9 gigatonnes of annual CO_2 emissions by 2050. It is estimated that 25% of this emission reduction could be achieved using renewable energy. Therefore, while climate change is a challenge to human society, it also presents opportunities for exploiting and developing renewable energy resources.

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