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Research article

Sustaining COVID-19 pandemic lockdown era air pollution impact through utilization of more renewable energy resources

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ABSTRACT

The lock down engendered by COVID-19 pandemic has impacted positively on the environment through reduction of the emissions of green house gases, CO_2, CO and other pollutants into the atmosphere below the pre-COVID-19 levels. There are fears that the gains made in the environment during COVID-19 may be frittered away as nations around the world make serious efforts to boost the COVID-19 recessed economy through massive investments in the sectors of the economy that are not environmentally friendly. This paper emphasizes on the essence of maintaining the COVID-19 pandemic era environmental impact levels in post COVID-19 era without retarding the efforts towards economic recovery. World health organization (WHO) data from six regions between April and August 2020 was evaluated. Emission levels during the COVID-19 lockdown were reviewed. The global renewable energy potentials were ascertained. The paper suggests that investment in renewable energy resources for various countries' energy needs will help sustain the green and clean environment created by the COVID-19 lockdown even after COVID-19 era lockdown. Also, building large scale and distributed energy storage infrastructure and application of artificial intelligence would ensure security of energy supply and handle unstable nature of solar and wind energy. The COVID-19 lockdown significantly reduced air pollution. The application of biofuels to generate energy and power was found to significantly reduce air pollutant emissions similar to COVID-19 lockdown.

1. Introduction

Corona virus emerged in Wuhan, the capital of Hubei province of China as a transmittable respiratory tract infection in November to December, 2019 (Lu et al., 2020). Before the end of June 2020, it spread to over two hundred countries, traversing all the continents: Europe, Asia, Africa, Oceania and the Americas. What started like provincial health challenge in China devastated the entire world, making mincemeat of the advances in medical, biological and microbiological sciences and technologies of even the most acclaimed advanced countries of the world. The epicentre of COVID-19 in the world was United States of America with over 3 million confirmed cases. China and Western Europe, specifically Italy and Spain were equally the epicentres of corona virus. With over 11 million confirmed cases and over 500,000 fatalities, the disease became a significant global health challenge. Corona-virus which was renamed COVID-19 on February 11, 2020 and declared as a pandemic on March 11, 2020 by the World Health Organisation humbled the world as the rich countries and the rich individuals were not only the most affected, but they seem helpless. Figure 1 shows the WHO reports of the most affected countries among the six (6) WHO regions in April 2020 and after about four (4) months latter (August 2020). Although from China where it originated it appeared that there was significant reduction between April and August, 2020 and efforts seem to be reducing the tension and pressure of this disease, yet the disease was still having high records of confirmed, death and new cases in most countries after four months of global, national and individual combats.

Considering American region, US had less confirmed and death records in August than April with its new cases higher by about 5,000. In all the cases, Brazil, Mexico and Peru had their April records less than that of August. However, the trend followed an increasing trend from Peru, Mexico and Brazil to US in August, 2020. Generally while some countries like Spain were recording zero (0) new cases in August against 4,167 new cases in April, India and Bangladesh that had zero (0) new cases in April date had 64,399 and 2,481 new cases respectively in August date. Also, Nepal from South East Asian region that had zero (0) death in April date was recording 79 deaths in August date. However, China showed a

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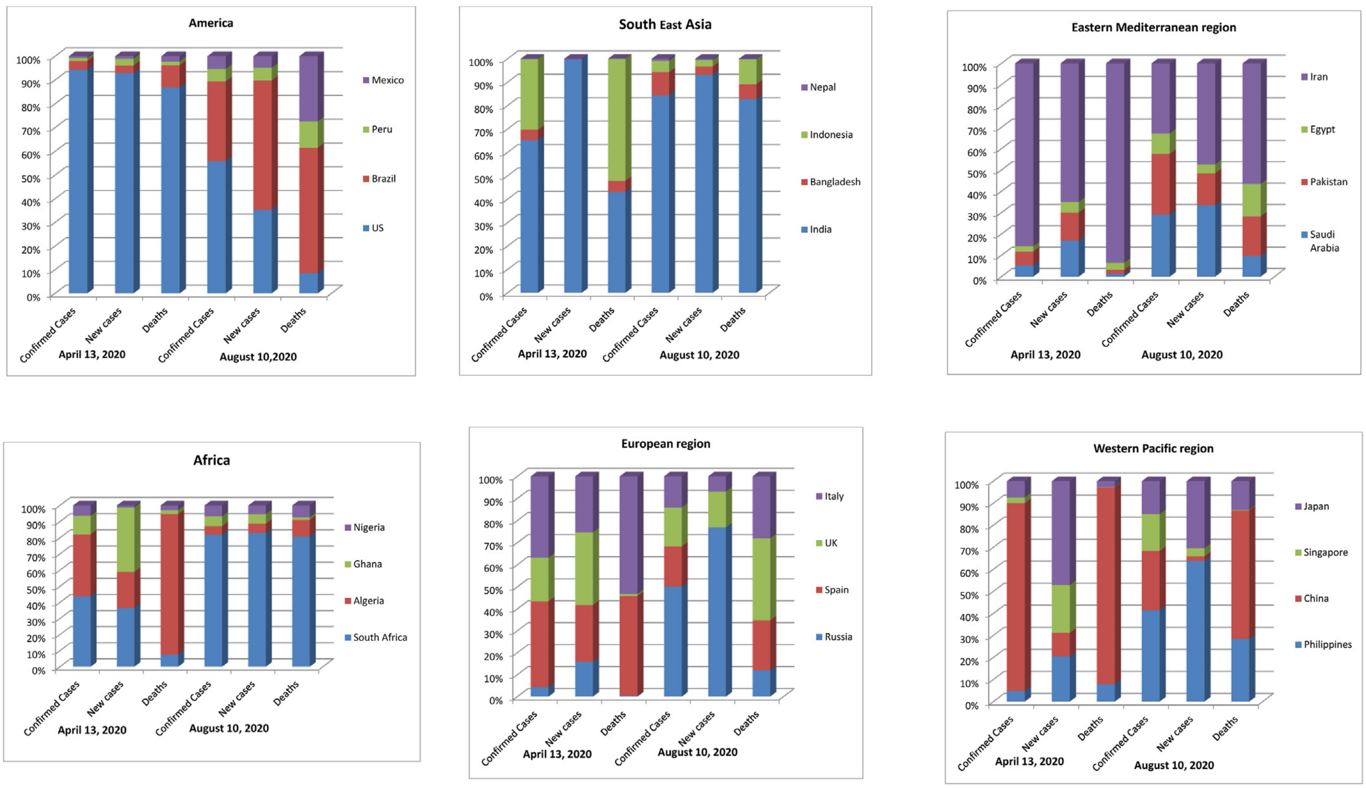


Figure 1. WHO reports on most affected COVID-19 pandemic regions in April 2020 and August 2020 (WHO, 2020).

drastic reduction in new cases. US appeared to be leading in death tolls in both April and August, 2020 dates, followed by Italy and Spain in April, 2020, and Brazil and Mexico in August, 2020 dates. West Pacific showed lowest records in both April and August of 2020 among other regions followed by Africa while America and Europe were the most affected by the pandemic. Nigeria like most economies that depend on commodity market, particularly oil as a major revenue earner was seriously affected by COVID-19 pandemic (Amzat et al., 2020; NCDC, 2020).

The health challenge posed by COVID-19 pandemic was the most traumatic experience the world had witnessed in this generation. Though basically a health challenge, the pandemic simultaneously impacted deleteriously on other aspects of the society including economy, education, religion, sports and the environment. The world was indeed unprepared for the virus and therefore lacked any adequate health response to the pandemic. Guterres (2020) recently reported that the world is facing a global health crisis unlike any in the 75 year history of United Nations and that human suffering and challenging global economy is at high rising rate. COVID-19 pandemic has indeed become a world scourge. The crises generated by COVID-19 in the world have assumed inexplicable proportion. The world leaders and states have taken measures that are unprecedented in a bid to contain and flatten the curve of the rampaging pandemic. These decisions in many occasions lulled the world into unsolicited holidays. The major cities of the world known for their all day long boisterous propensity were observed unwittingly going into hibernation. The decisions made by people and governments in the heat of COVID-19 pandemic will shape the present and future world in terms of health care, economy, culture, politics and environment (Yuval, 2020).

The effect of the COVID-19 pandemic on the different spheres of the global life has been overwhelming. The aviation industry has been one of the most affected. The ban on air travel and consequent closure of airports for national and international travels except on essential situation around the world did not only affect the aviation business but indeed retarded the economic activities in the tourism, hospitality, manufacturing and construction sectors globally. The world commodity market is already feeling serious knuckles and most mono-cultural economies faced unprecedented crises. The lull in the transport, manufacturing and industrial activities created a serious demand and supply crisis in the world oil industry. The global economy according to the Britton Wood institutions (the World Bank and the International Monetary Fund) faced a COVID-19 pandemic induced recession (Abati, 2020). It is believed that the COVID-19 pandemic will change the global market from seller's market to buyer's market resulting in weakening the political and monopolistic attributes of oil and gas. Global economic recession is likely had negative impact in the efforts to achieve other critical global sustainable development goals (SDGs) such as global food security, ending poverty in all its forms everywhere, ensuring high quality education for all and providing all people with access to water and sanitation, particularly in the third world countries (Okereke, 2020).

While the COVID-19 pandemic inflicted substantial economic and social shocks, it also profoundly impacted well on the environment in various ways. The concern for the environment is a manifestation of the fact that the environment is bound up with health, economic, psychological, social and, indeed, all other aspects of man's efforts in his survival strategy (Tunji and Ajibola, 2008). It is not surprising that issues of environment occupy prominent positions in the targets of Millennium and Sustainable Development Goals. The United Nations has shown great efforts at addressing environmental issues. The world environment has become so degraded due to natural and human conduct through the depletion of the resources such as air, water and soil; the destruction of the ecosystems; habitat destruction; the extinction of wild life and pollution. A combination of large and increasing population; expansion of complex economic activities and the application of resource depleting and polluting technology have compounded the already deteriorating environment (Nyango, 2008). The high use of fossil fuel, traditional biomass, coal and other non-renewable energy sources has also exacerbated the degradation of the environment. The evidence of climate change engendered by the assault on the environment comes with its consequences of increasing combustion emissions, rise in sea levels, heat waves and heat conditions, flooding and loss of lives (Okereke, 2020).

However, COVID-19 pandemic and the policy measures put in place to contain the spread which have lulled human activities in sea, air and land transportation, manufacturing and construction has fortuitously improved the environment through improvement in air quality, reduction in carbon dioxide emissions and mitigation of urban pollutant emissions. There are still fears that the unintended environmental gains recorded via COVID-19 pandemic lockdown may be reversed when human activities resume post COVID-19 pandemic. The post COVID-19 pandemic environmental concerns are obvious because if not well managed, the nations' rush to replenish lost grounds may precipitate enormous economic activities that may worsen the pre-COVID-19 pandemic environmental situation. The aim of this paper is to articulate ideas that will encourage the policy makers and stake holders in energy and power generations and utilization to sustain the environmental gains made in favour of the environment during the COVID-19 pandemic lockdown. This can be achieved through investing more into environmental green technologies as well as reinvigorating renewable energy policy measures.

2. Conceptualising COVID-19 lockdown impact on the environment

The wide spread of corona virus has affected the social and economic lives globally but more importantly the developing economies have been hit hardest. This is part of the consequences of the drastic decisions the world must take to contain the spread of corona virus and at the same time address its concomitant consequences. These decisions have their onerous impact on the social, psychological, economic and political life of the nations, communities, families and individuals. Governments around the world have provided economic stimulus and palliatives that combine economic, social and psychological packages to deal with the impact of the lock down on their citizens.

Lockdown involves the restriction of movements, shut down of economic activities and restriction of social engagements. Lockdown ranges from closing of airports for international and local air travels; shutting down of motor parks to prevent inter and intra-city travels, closing schools, markets and industries; clamping down on social activities like weddings, burials, parties, clubbing, sporting activities and other forms of celebrations; ending all forms of religious activities and closure of intra and international borders; to enforcing stay at home order. Only the essential activities such as food and related business, pharmaceuticals, medicals, utilities, banks and communication are allowed to operate. The aim of the lockdown is to reduce the crowding of people which increases the possibility of massive community transmission. No doubt, COVID-19 pandemic lockdown has lulled businesses, slowed economic activities and hampered social engagement. During the outbreak of COVID-19 pandemic in China, there was significant decrease in traffic and soil and aged salt by 70% and 68% respectively (Dai et al., 2020). Although COVID-19 pandemic has resulted in slight increase in methane emission level through several cuts in agriculture and Fishery activities, the COVID-19 pandemic has generally been benevolent to the environment. COVID-19 has in the main helped to achieve what the global efforts over the years has failed to achieve with the environment. The world will be better endowed if the governments around the world will ensure the sustenance of COVID-19 pandemic environmental situations in the post COVID-19 pandemic era. China recorded about 42% decline in total electricity consumption in the first quarter of 2020 due to COVID-19 pandemic. There is a decrease in the use of coal by power plants and Indian's electricity production through the coal-thermal plants reduced by 65 GW. Also, there was a decline in oil consumption as a result of the recession in the global manufacturing and transportation industries. The IEA had reported that the 2020 fuel demand except renewable resources would shrink significantly more than what was observed in the last decades (Jin and Kiu, 2020). The UN says carbon emission must fall by 7.6% annually through 2030 in order to reduce global warming to 1.5 °C by 2100. Experts have predicted that if economic activities resume by mid-June 2020, the decline would be around 4% but if it remains globally till the end of 2020, 7% would be the decline. The IEA has proposed ‘major slight’ to low carbon sources of power such as wind and solar which shall comprise 40% of global electricity generation. The impact of COVID-19 pandemic lockdown on the environment has been palpable. Table 1 shows that the restrictions in air, sea and land travels has improved air quality because of significant reduction in the emissions of carbon dioxide and nitrogen oxide with increase in related ozone (O_3) when compared to 2019 levels of the same period (Earth Matters, 2020). Although, ozone was found to increase which has been explained to be due to lower titration of O_3 by NO due to strong reduction in local NOx emission by road transport, there was quite significant reduction in NOx and PM (Perre et al., 2020).

The restrictions in sea transport and economic activities such as fishing and mining also means that sea pollution has reduced significantly and the life in the sea for the fishes and other animals has become bubbling once again. The ban in manufacturing and industrial activities and the reduction in the use of nonrenewable energy have also helped in the reduction of greenhouse emissions which in the long term will mitigate climatic conditions. By controlling the effect of climate change, the world particularly the less developed part of the world with dearth of infrastructure will be saved the consequences of climate change such as heat wave, flooding, sea rise and unhealthy conditions. Recent data released by National Aeronautic and Space Administration (NASA) and European Space Agency (ESA) indicate that pollution in some epicentres of COVID-19 pandemic such as Wuhan, Italy, Spain and United States of America has reduced by 30% (Mohammed, 2020). At the peak of COVID-19 pandemic in China, COVID-19 was only the 49th cause of death. Stroke was the highest (above 170,000 death), followed by Isch. heart diseases (about 150,000 deaths) according to IIASA, 2020, China CDC 2020 and IHME, 2017. Also, although, Italy at the same time had more than 15 times the total confirmed corona virus cases than China with death records surpassing China's toll, yet COVID-19 was observed to be the 8th cause of death in February/March, 2020. Equally, The lockdown and sit at home and work from home must have equally reduced the number of death that could have occurred due to commuter accidents through vehicular movements and as well as that resulting from exposure to environmental hazards and related pollution. Therefore, it will be very hard to conclude that high death toll resulting from COVID-19 mortality correlated with the low emission observed during the COVID-19 pandemic lockdown in February 2020.

The estimated total change in emissions from Covid-19 pandemic amounts 1048 million tonnes of CO_2 till end of April 2020. The global changes are presented in Table 2 while the percentage effect according to activity is contained in Table 3. The decline of major air pollutants in early 2020 compared to 2019 is presented in Table 4.

Researchers have equally reported dramatic reduction of particulate matter of 2.5 μm in main Chinese cities (Table 5), NO_2 reduction in France, Germany, Italy and Spain as well as reduction in noise (Manuel et al., 2020). A drop of 20–30% of PM 2.5 in comparison with monthly average of February 2020, February 2017, 2018 and 2019 is observed. All these air quality improvements generated human health benefits that have outnumbered confirmed SARS-COV2 deaths thus far (Chen et al., 2020). Basically, reduction in car use, halting of power plants and industrial activities, strong social distancing, clean-up of beaches and reduction in tourism activities, reduction in commercial activities and increase in online shopping for home delivery helped to reduce the emissions. However, these activities cannot have long term sustenance to prevent the total collapse of the global economy. Therefore, the best solution to sustain the good news of global reduction in emissions and positive climatic change without negative effect on the global economy is to harness without reservation the various renewable energy potentials and technologies.

Table 1. COVID-19 lockdown era emission reduction 2019–2020 (Earth Matters, 2020).

Sn	Emission	% Reduction/increase
1	CO_2	25↓
2	NO	30↓
3	O_3	30↑

↓- decrease, ↑-increase.

Table 2. The estimated total global change in CO_2 emissions from COVID-19 pandemic.

Countries	Emission change (million tonnes)
China	242
US	207
EU	123
India	98
UK	18

Table 3. Outcome of 69 countries economic activity effect on emission reduction.

Activity	% effect
Land transportation	43%
Industry and power	43%
Aviation	10%

Earth Matters (2020).

3. The world environment and the need for COVID-19 environmental sustenance

The challenge of environmental despoliation has been a major concern of the world more now than ever before, because environment is man's life support system. Therefore, as man affects the quality of the environment, so the environment affects the quality of man's life (Tunji and Ajibola, 2008). Environment thus provides numerous opportunities for wealth creation and employment opportunities for human exploration and exploitation. However, man's capacity to explore and exploit the environment has taken on a more dangerous dimension in the last three decades. Much of the environmental problems that have impacted on human health, economy and resource availability, are direct consequences of industrialisation, exploration, mining, military and transportation activities across borders (Dalby, 2013). The United Nations Environmental Programme revealed that the intensified unsustainable demand for land, water marines and coastal resources, resulting from the expansion of agriculture and uncontrolled urbanisation, lead to increased degradation of natural eco system and also erode the life supporting system that uphold civilization (Payne and Nasser, 2003).

Environmental degradation is the deterioration of the environment through the depletion of the resources such as air, water and soil; the destruction of the ecosystem; habitat destruction; the extinction of wild life and pollution. It is any change or disturbance to the environment perceived to be deteriorations or undesirable. The United Nations Environmental Programme (UNEP, 2019) has expressed profound concern that the degradation of the environment may lead to the reduction of the capacity of the environment to meet social and ecological objectives and needs. The environmental degradation is more pronounced in less developed countries where the infrastructure is lacking and the technology for green economic revolution is at very low ebb. There has thus been massive investment in non-renewable energy such as fire wood, coal and fossil fuel as major source of energy as against the renewable energy such as solar, biomass, thermal and hydro. The result of the environmental problems is pollution of the air through the massive emission of carbon dioxide and carbon monoxide that lead to disastrous climate change with consequences of flooding, erosion, unbearable heat, desertification, and decline in agriculture and health complications. It is clear that environment polluted by various emissions from industry promotes high respiratory diseases such as asthma and people who suffer from respiratory diseases are more prone to COVID-19 diseases. Therefore, clean environment would equally be a better way of combating the spread COVID-19 and other related diseases.

The concern for the environment has become so global that representation at international conferences to discuss global environment has been at the highest level of governments. The first international

Table 4. The decline of major air pollutants in early 2020 compared to 2019.

Country	Air pollutants reduction		Major causes
	Pollutant	% reduction	
27 countries	NO_2	13–44%	Closure of factories, transportation networks, and companies.
	O_3	2–20%	
	$PM_{2.5}$	10–28%	
New York (USA)	CO_2	5–10%	Closure of factories, transportation networks and companies.
China, Italy, France and Spain	NO_2	20–30%	Closure of factories, transportation networks and companies.
USA	NO_2	30%	
India	NO_2	40–50%	
Delhi (India)	$PM_{2.5}$	200%	Restricted travel including flights, rail, intercity bus services and industrial activity stopped.
	PM_{10}		
Western Europe	NO_2	30–50%	-
	PM	5–15%	
Sao Paulo (Brazil)	CO	64.8%	Closure of shopping malls, restaurants, fitness centres, schools, universities and public transportation restrictions.
	NO	77.3%	
	NO_2	54.3%	
Barcelona, Madrid (Spain)	NO_2	50%	Decrease in vehicular mobility and the volume of other relevant activities such as port and airport operations.
		62%	
Rio de Janeiro (Brazil)	CO	30.3–48.5%	Vehicle circulation restrictions, suspension of classes, and many other activities.
	NO_2	16.8–53.8%	
	NO_x	24.4–46.1%	
Wuhan (China)	$PM_{2.5}$	25%	-
	NO_2	40%	Use of diesel vehicles stopped.

Table 5. SARS-COV2 lockdown emission change (Manuel et al., 2020).

S/N	Emission/cities	Reduction/increase
1	NO_2 (Wuhan)	22.8 μg/m^3 ↓
	NO_2 (China)	12.9 μg/m^3 ↓
2	$PM_{2.5}$ (Wuhan)	1.4 μg/m^3 ↓
	Other Cities (367)	18.9 μg/m^3 ↓
3	NOx (France)	70% ↓
4	$PM_{2.5}$ (France)	10 %↓
5	O_3 (South Europe)	17%↑
6	O_3 (Wuhan)	36% ↑
7	NOx (South Europe)	49%↓
8	PM (Wuhan)	42%↓
9	PM (Europe)	8%↓
10	NOx (all cities in China)	56%↓
11	$PM_{2.5}$ (New York city)	36%↓
12	NO_2 (New York city)	5%↓

↓-decrease, ↑-increase.

conference on the threat of global environmental degradation was held in Stockholm in 1972. In 1974, the United Nations International conference on global environmental issues held in Bucharest adopted June 5, every year as the World Environmental Day to raise awareness on the essence of a healthy environment for the world population. In 1994, The United Nations conference on Environment and Development also known as the Earth Summit was held. The 2000 Millennium declaration on environment pointed out that improved governance; reduced poverty and environmental stewardship are inseparable. The Millennium Development Goals assert that the integration of principles of sustainable development into country policies will help to combat degradation and loss of environmental resources. Again, the Rio De Geneiro Earth Summit of 2002 in its Principle 25 on "Environment and Development" recognized that Peace, Development and Environmental protection are interdependent and indivisible (Frankel, 2005).

The 2015 world conference in France reached some far reaching agreements on the need for better global environment generally referred to as the Parris Agreement. Couched within the United Nations Framework Convention on Climate Change (UNFCC), the Paris agreement aims to substantially reduce global greenhouse gas emissions in an effect to limit the global temperature increase in this century to 2 degree Celsius above pre-industrial levels. The agreement targeted a reduction of carbon dioxide emissions by 20% through the extraction from all emitting countries to cut their climate altering pollution over time. Most importantly, the agreement craved for an increase of renewable energy's market share to 20% through a 20% increase in energy efficiency (Denchmark, 2018). About 200 countries including the United States of America committed to addressing climate change and its negative impacts through the Paris climate agreement. The agreement came with certain economic consequences for the nations. Though a few nations led by the United States of America (USA) later reneged on the agreement, many nations have ratified the Paris Agreement. Nigeria for instance ratified the Paris Agreement in May 2017 with a promise to reduce carbon emission by 20% by 2030. This is however a tall dream for Nigeria because of the economic implications. The major problem therefore is the implementation of the ratified agreement. For instance, one way of speedily achieving the Paris protocol is by stopping gas flaring and redirecting the gas to energise power and boost the domestic use of gas as cooking fuel in the country. But many years of efforts by the government has not achieved the end to gas flaring by the oil companies in Nigeria. Also, the dilemma of both investing in basic infrastructure, health and education; and investing in the green economy presents another challenge because of the parlous economy. This is compounded by the world recession that stalled the capacity of these nations to achieve other sustainable goals of ending poverty, providing food security and water rather than investing environmental friendly technologies. It therefore boils down to a matter of priorities.

The above situations are compounded by the COVID-19 pandemic induced economic difficulties. The lockdown enforced to contain the spread of the pandemic around the globe has led to a constriction on the economy which has placed severe limits on efforts to a review of the budgets. In the process, allocation to environmental problem mitigation and the implementation of international agreements on the green economy initiative has been affected. However, COVID-19 pandemic has provided a window of opportunities towards sustaining clean environment. The lull in transportation, manufacturing, construction and mining has led to reduction in emissions of pollutants beyond the limits demanded by international agreements, improvement in air quality and mitigation of the crises of climate change. The challenge before the society and the policy makers is to sustain the environmental gains from the COVID-19 pandemic era as the world march into the world of post COVID-19 pandemic. It is however most likely those nations around the world may think less of green initiatives as they contend with efforts at the fast recovery from the impact of COVID-19 pandemic on the macro economy. Sustaining COVID-19 pandemic era environmental friendly initiative require that governments should roll out economic stimulus packages to assist the transport companies and industrial manufacturers to include provisions for large emissions reduction technologies in their post COVID-19 pandemic operations. Such encouragement could help to prevent pollutant emission levels from rising to pre-COVID-19 pandemic levels. This can also be achieved through massive investment into renewable energy sources.

4. Sustaining COVID-19 era lockdown environment through renewable energy resources

4.1. Challenges of fossil fuels' candidature

Energy and power would become a very crucial factor for human activities, economic growth and high standard of living to be realized after the COVID-19 Lockdown era. Global projected percentage change in energy consumption between 1990-2040 is presented in Table 6 while the share of individual primary energy source in meeting future energy needs is contained

Table 6. Global projected percentage change in energy consumption between 1990-2040.

Region	1990–2016 (% change per annum)	2016–2040 (% change per annum)
US	0.6	0.0
Brazil	3.4	2.0
EU	-0.1	-0.5
Russia	-1.0	0.3
Middle East	4.8	1.8
Africa	2.7	3.5
China	5.9	1.5
India	5.2	4.2

Table 7. Share of individual primary energy source in meeting future energy needs (%).

Source of Energy	1998	2025	2050
Fossil fuels	88	62	29
Nuclear energy	10	2	2
Hydrogen from solar	-	7	31
Electricity from solar	-	11	16
Heat from solar	-	18	22
Hydrogen from solar	2	25	35
Hydrogen	-	11	34

Source: (Balat and Elif, 2010).

Table 8. World energy investment from 2017-2020.

Year	Expenditure in fuel supply ($billions)	Power sector	Energy end-use and efficiency
2017	850	782	280
2018	854	769	281
2019	854	757	280
2020	595	678	247

in Table 7. This is very counteractive considering the fact that the International Energy Agency has reported the world would need 50% more energy in the next 10 years (2030) than today (Esonye et al., 2019a) while the world energy demand is estimated to be about 1000 EJ by 2050 (Moriarty and Honnery, 2012). Fossil fuels are limited in reserves and concentrated in certain regions of the world and they are at the verge of reaching the peak in less than 40 years. Also, 4.1 billion metric tonnes of CO_2 will be released to the atmosphere in the next 15 years (2035). The deep water horizon spill released 4 million barrels of oil into Gulf of Mexico while the islands resulted from overuse of asphalt caused high mortality in the urban centres. The world oil reserve is predicted to deplete out in less than four decades to come (Esonye et al., 2019b). Also, every benefit from petroleum is accompanied with environmental ramification while combustion engine emissions have resulted in serious concern over air quality and greenhouse effect. It is reported that about one million living species and hundred millions of people could lose their lines if the global temperature increases by more than 20 °C (Esonye et al., 2019a, b, c, d). Also, as supply of fossil fuels dwindle and there is a great concern about continued problem of high pollutant emission from fossil fuel combustion, renewable energy is expected to play a vital and major role in the global future energy provision. It is predicted that the COVID-19 pandemic will accelerate to exit of coal with renewable energy resources taking a lead (Jin and Kiu, 2020). During the pandemic, the amount of electricity generated from renewable energy reached a high record while India is currently deploying more solar and hydro-electric power stations (Jin and Kiu, 2020). European space agency has shown that the level of NOx and other air pollutants over Europe, united States, China and other areas significantly decreased since the beginning of the pandemic. The distribution of the global energy consumption of fossil energy and its attendant environmental negative effects will make achievement of clean environment to be farfetched. This can be reversed with a change of policy towards more integration of renewable energy resources. This has become imperative with opportunities and possibilities provided by COVID-19 pandemic lockdown. Also, Renewable energy is currently receiving great attention in the midst of the pandemic for economic depression recovery as follows:

1. China has issued a notice of promoting financial subsidies for electric vehicles in April 2020
2. China's state Grid Corporation has launched a new round of charging piles construction in April 2020 with the intention of deploying about 78, 000 charging piles which will help to promote the recovery of related sectors affected more by the pandemic.
3. European Union included a green transition in their COVID-19 strategy to increase photovoltaic deployment.
4. Israeli government is planning to invest $7.1 billion for energy and water infrastructure construction with $1.8 billion meant for 2.0 GW photovoltaic power generation facilities. From Table 8, there is a sharp decrease in the global energy investment in 2020 during the COVID-19 lockdown.

4.2. Renewable energy resources potentials

Renewable energy generally applies to the energy resources whose common characteristics are that they are non-exhaustible and naturally renewable. They are sources of clean inexhaustible energy and increasingly competitive (Mizik and Gyarmat, 2021). Renewable energy resources are based on environmentally friendly technologies that convert biomass, solar, thermal or hydro powers to electricity and motor power. Renewable energy differs from fossil fuel because they are naturally renewable, diversified, abundant and sustainable; while fossil fuel is earth endowed fixed non-renewable fuel stock. Fossil fuels include coal, petroleum, natural gas, tar sand, oil shale, nuclear fuels (uranium, thorium, deuterium and lithium). Many renewable energy sources abound such as: wind, solar, hydro, biomass, geothermal, tidal wave etc. (Bigwhiz, 2020). Renewable energy promotes environmental, cost and policy benefits. Renewable energy is clean energy that is developed by renewable energy is vital for combating climate change and limiting its devastating effects. Recently, catalytic converters in cars helps in reducing CO_2 emissions through CO conversion to CO_2 (Yin et al., 2015). Equally, working from home provides benefits that help to reduce greenhouse gas emission, fuel usage, office waste and energy usage. All these have huge complimentary role in air pollution reduction and translate to cleaner and greener environment since daily commute of millions of people which results in the release of millions of tons of toxic pollutants are reduced. Also, despite the use of electric vehicles, current fossil fuel consumption is still high and remote workers drive less and this reduces the consumption of these fuels. However, renewable energy plays a complimentary role in the reduction of carbon dioxide (CO_2), carbon monoxide (CO) and other harmful pollutants in the atmosphere. It constitutes the biggest source of electricity globally although it is greatly under exploited. Renewable energy produces affordable power to electricity users because it is sustainable. This is because renewable energy cuts electricity bills because investment in it last for a longer time because it is naturally renewable. Renewable energy is therefore cost effective for individuals, communities and nations (Suray and Prabodh, 2021). The renewable energy resources make up 26% of the world electricity today (Mohammed, 2020). Few years ago, the world energy consumption had 78.4% belonging to the fossil fuel, 19% to renewable energy and 2.60% to nuclear energy (Figure 2a).

4.2.1. Global abundance of renewable energy resources

Generally, renewable energy is receiving concentrated attention globally in installed capacity (Table 9), employment (Tables 10 and 11), and investments (Table 12). The world has an abundance of renewable energy resources that can be exploited to create enormous power source to achieve a green economy. Some of the world's renewable energy resources include: hydro, wind, biomass, solar etc. The relative abundance of these resources in different countries of the world is presented in Figure 3. It has been predicted in the next 10 years, the world would need 50% energy more than currently required. There are over 350 oil bearing crops in the world that can be sources of feedstocks for biodiesel production with over 0.107 billion tonnes in 2000 and global consumption volumes was only 192.9 million tonnes in 2017 (Esonye et al., 2019c). The global biofuel consumption is presented in Table 13 while Table 14 contains the percentage energy mix of electricity supply of India, China and Germany. Also, for the EU countries, to make biofuel relevant players in the fuel market, tax exemptions and other policy instruments (quotas) have been suggested by (Ajavomnic and Hass 2010).

Likewise, comprehensive efficiency improvements and continuous developments towards 2nd generation biofuels would support the above approaches. For example in India, estimated renewable energy potential will be 225 GW by 2022 exceeding 175 GW pledged during the Paris agreement (Kumar and Majid, 2020). It is predicted that the portion of renewable power will be 10.2% by 2022 while renewable power technologies made 13.4% contribution to the cumulative power production in India by 2018. A gross of 1,990.37 MW, 70,564.0 MW and 1,527.3 MW of renewable energy installed capacity by state government, private and central government ownership respectively were provided in 2018. The above records contains 4,517.45 MW of small hydro power, 35, 138.15 MW of wind power, 9,075.50 MW biomass cogeneration, 138.30 MW waste to heat and 2,5212.26 MW of solar power. The percentage of renewable energy shares in the total installed capacity will rise from 3% in 2002 to 35% in 2032.

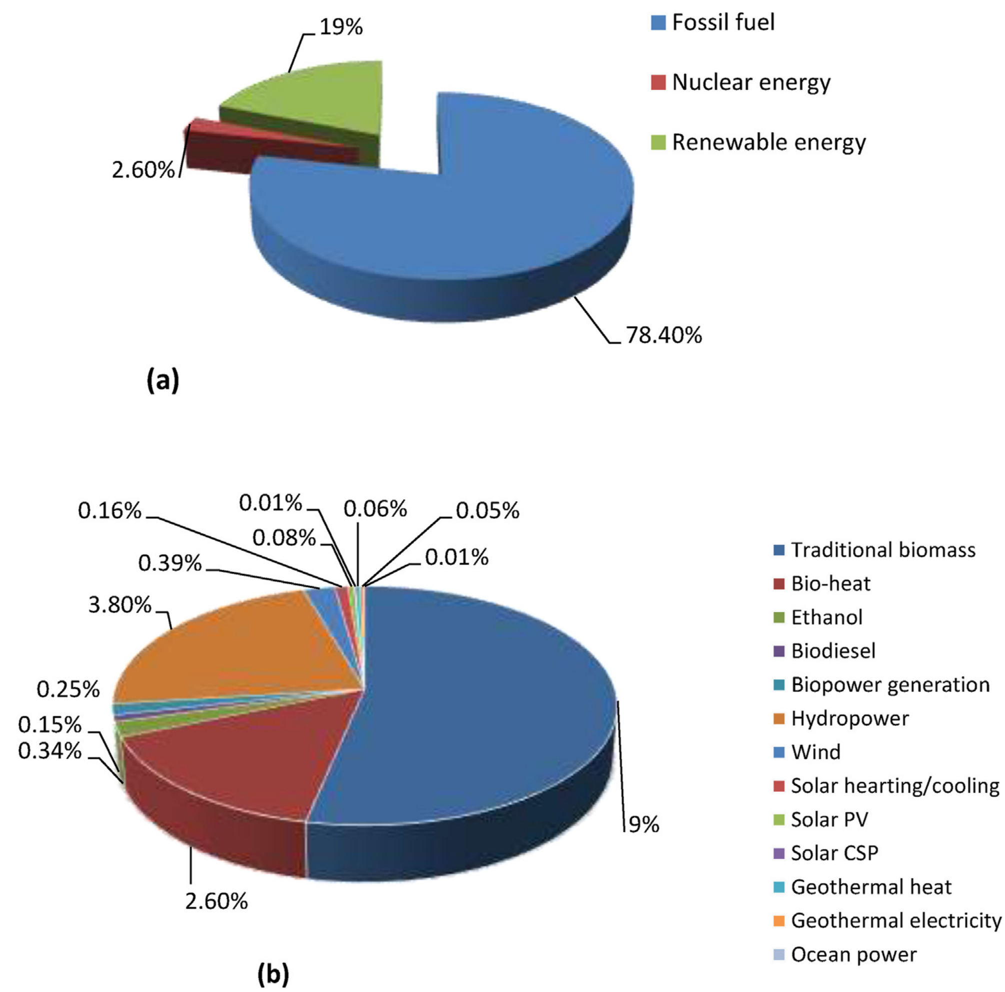


Figure 2. (a) Global energy consumption (b) Global renewable energy consumption (REN, 2017).

Additionally, biomass gasification has been proven to offer the earliest and most economic route for the production of renewable hydrogen (Balat and Elif, 2010). The projected world primary energy demand by 2050 is expected to be in the range of 600–1000 EJ compared to about 500 EJ in 2008 (Balat and Elif, 2010). The main greenhouse gas is CO_2 which is related to global warming. The transport sectors accounts for one-fifth of global CO_2 emission which is equivalent to 60% of global oil consumption. Consequently, the use of ethanol, biodiesel and hydrogen will play a vital role in future (Calle-Asensio et al., 2021). The EU has shown serious commitment to reduce the greenhouse emissions through the use of renewable energy fuels. Tax exemptions for biofuels used in transport sectors has been the key tool in Netherlands and other European countries.

The sustainable millennium goals (SDGs) of the various nations require sustainable energy policies. These policies can only be robust if the government goes green and renewable. In US, many policy initiatives and incentives have been made in favour of production of bio-ethanol from corn. This is believed to have helped to increase corn prices and farmers' income, enhance rural employment, encourage value-added businesses, increase energy security and produce fuels that reduce pollutants and greenhouse gases (Douglas, 2009). The target was to produce 7.5 billion gallons of biodiesel and bio-ethanol before 2013. US congress has taken serious measures to ensure that production of ethanol from corn grain starch provides about 10% of her natural gasoline usage (15 billion gallons) and this measure preserves more corn for domestic livestock producers (Douglas, 2009). New investments on renewable sector increased from 39.5 billion dollars in 2004 to 214.4 billion dollars in 2013 with 16.7% in USA, 26.3% in China, 22.6% in Europe, 20.2% in China and India, 5.8% in USA and Brazil, 4.2% in middle East Africa, 2.8% in India and 1.4% in Brazil. Although, the bio-ethanol production and development in Sub-Saharan Africa (SSA) is yet to level with other regions, it is foreseen that by the year 2050 the potential for bio-ethanol in SSA will increase from its current production of 347 EJ to about 1548 EJ (Evanie et al., 2012). The government of Thailand has announced that it needs to increase the acquired share of alternative energy from 6.4% to 20.3% of commercial primary energy by 2022 (Chairprasert, 2011). Currently, there exists biofuels policy in most sub-Saharan African countries. The selected country biofuels policy developments are presented in Table 15. However, it should be noted that in Brazil where ethanol blend fuels are being largely used, there is high rise in ambient concentration of certain volatile organic carbons (VOC) such as acetaldehyde and formaldehyde which is viewed as many times higher than

Table 9. Global installed capacity of renewable energy by 2017.

Sn	Source	Amount (GW)
1	Ocean energy	0.5
2	Wind energy	539
3	CSP	4.9
4	Solar PV	402
5	Geothermal power	12.8
6	Bio-power	122
7	Hydropower	1,114

Table 10. Global renewable energy employment (Josef et al., 2018).

Sn	Region/Country	Total number of jobs (million)
1	Africa	76
2	Japan	283
3	Germany	332
4	India	432
5	USA	786
6	Brazil	893
7	EU	1,268
8	China	3,880

Table 11. Global renewable energy employment (Josef et al., 2018).

Sn	Source (million jobs)	2012	2014	2017
1	Solar (PV)	1.36	2.5	3.37
2	Biofuels	2.4	2.99	3.06
3	Wind	0.75	1.03	1.15
4	Solar heating	0.89	0.76	0.81

Table 12. New Investments in renewable energy in $bn (Bergmann et al., 2006; Kumar and Majid, 2020).

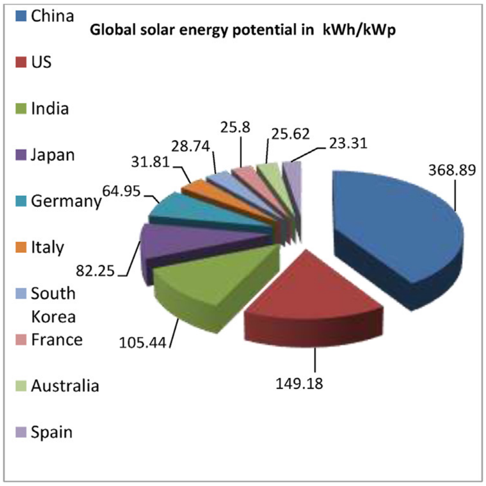
Country	2005	2010	2017
USA	16.5	46.6	56.9
Europe	38.9	123.1	57.4
China	8.8	45.0	132.6
Brazil	2.7	7.5	6.2
Canada	2.1	6.6	3.3
Mexico	0.2	2.5	6.2
UK	4.7	10.8	10.3
Germany	13.2	40.3	14.6
France	3.2	6.3	5.0
Spain	5.2	8.1	1.1
Italy	2.4	24.3	2.5
Japan	8.4	14.8	23.4
India	3.2	9.0	11.0
Australia	1.4	5.2	9.0

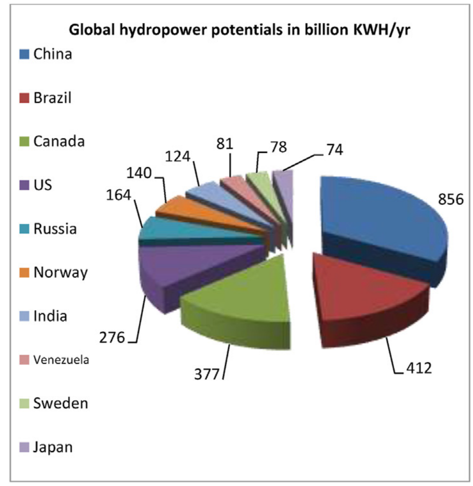
observed in other countries with the limited use of biofuels (Acheampong et al., 2016). Alvim et al. (2018) have observed that between September 2011 to August 2012 VOCs were major precursors in O_3 formation with acetaldehydes contributing 61.2%. The authors suggested reducing VOC emissions as an important route to limiting O_3 levels. Also, Gaffney et al. (1999) observed between February–March 1997 that peroxybutryl nitrate (PBN), peroxypropionyl nitrate produced in mega city of Mexico are likely to contribute to increase in regional ozone and aerosol productions during long term transport. They reported that MTBE/gasoline fuel usage is equally a key source of isobutene and formaldehyde. Interestingly, chemical reaction kinetic studies have shown that formaldehyde concentration peak can be significantly reduced with the increase in intake temperature, intake pressure, exhaust gas recirculation ratio and reduction in compression ratio (Li et al., 2017).

Kin and Dale (2005) have reported earlier that utilizing biofuels derived from biomass would save nonrenewable energy and reduce greenhouse gases. However, the authors suggests planting of cover crops as necessary measures to prevent increase in acidification and eutrophication which results from the release of large nitrogen and phosphorus related environment burdens from soil during cultivation. Another very challenging issue on biofuels application relating to LCA is the extraction and emissions of biogenic CO_2 and CO product allocation (Voet et al., 2010). Different approved methods of allocation by International Organization for Standardization for LCA Studies can provide improvement percentage compared with fossil fuels. When operating at a continuous steady state, renewable energy derived from biomass is seen as carbon neutral as their carbon emissions as a result of biomass combustion is balanced out by carbon fixation during biomass growth (Song et al., 2015). However, the above simplistic proposition did not consider the life cycle assessment (LCA) of biofuels and emissions that could take place due to land use charges. Although there are issues raised against realisation of biofuels from biomass such as fuel version food debate, low performances in cold temperatures, reduction in available arable land for farming. The use of non-edible feedstocks, availability of marginal land resources for farming and use of anti-freeze and improvement materials in engines have been suggested to be ways of arresting the problem (Gressel, 2008). However, Life Cycle Assessment (LCA) of various biomass applications for power has shown that modernized bio-energy systems have significant impact on mitigation of climatic change, development of rural areas and employment of options with provision of alternative energy formula (Plieninger et al., 2006). Although leaving forests for standing to serve as carbon sinks against using their biomass for biofuels to give better releases due to reduction in GHGs have been controversial (Kirschbaum, 2003), a fossil fuel substitution efficiency of 50% has been reported to have same capacity as forest kept in perpetuity (Acheampong et al., 2016).

Volatile organic compounds (VOCs) which include aldehydes, alkenes, ketones, aromatics and halogenated hydrocarbons, are among unregulated emissions which affect negatively normal metabolism of the human body and cause acute allergies (Wu et al., 2020). Many researchers have proven that biodiesel blends of about B20 fuel blend releases less total VOCs than conventional diesel (Peng et al., 2012; Ge et al., 2018) more especially at higher engine speeds (Shahab et al., 2009). Also, although polycyclic aromatic hydrocarbons (PAHs) are among unregulated gases, their emissions creates harmful conditions resulting in cancer, cell malfunctions and impaired lung functions (Kim et al., 2013). PAHs emitted by diesel engines come from fuel during combustion, accumulation from fuel during combustion, accumulation from fuel to lubricating oil as well as PAHs generated from fuel pyro-synthesis processes (Wang et al., 2013). Both biodiesel and petrodiesel release PAHs on combustion but biodiesel has fewer polycyclic aromatic hydrocarbons and consequently granular phase aromatics generated during their combustion is reduced (Wang et al., 2013). Also, the higher oxygen content in biodiesel which has the tendency of yielding complete combustion and thereby reducing PAH emissions (Borillo et al., 2018). Many researchers have therefore successfully obtained 28% and 37.7% PAHs emission reduction from waste cooking oil biodiesel compared to ultra-low sulphur diesel. However, some authors have suggested that application of nano-additives can be used to decrease NOx emission of biodiesel (Wu et al., 2020). However, the operation of the diesel engine at excess air coefficient higher than 1.7 and fuel pre-treatment using hydrogen, CO and methane have been reported as best practices that drastically reduce formaldehyde of biodiesel (Li et al., 2017).

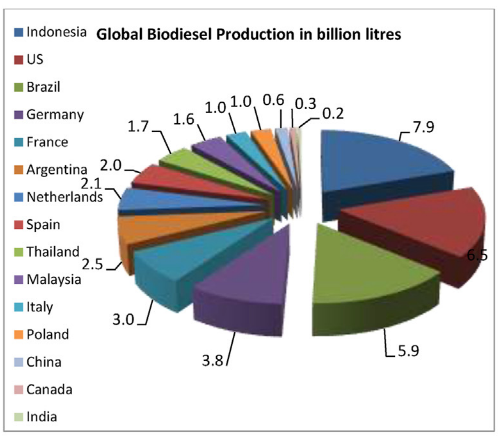
4.2.1.1. Biodiesel potentials. Table 16 shows some of the results obtained in support of the viability of using biodiesel fuel in combustion to reduce environmental pollution, and atmospheric degradation in comparison with petrodiesel usage. Many researchers have established significant reduction in combustion emission by using biodiesel as well as bio-ethanol in combustion engines (Esonye et al., 2019d). The maximum biodiesel market penetration would be about 9% in 2030 with a wholesale diesel price of $4.00 per gallon (Kenneth and Bruce,

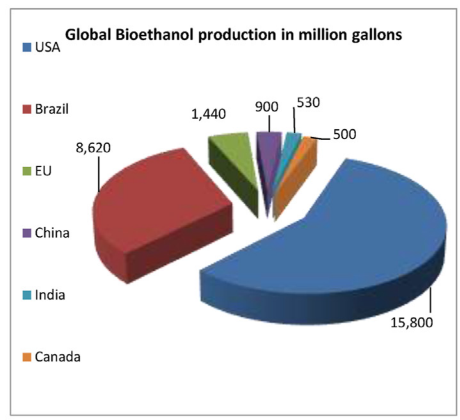




(a) Source: ESMAP, (2020)

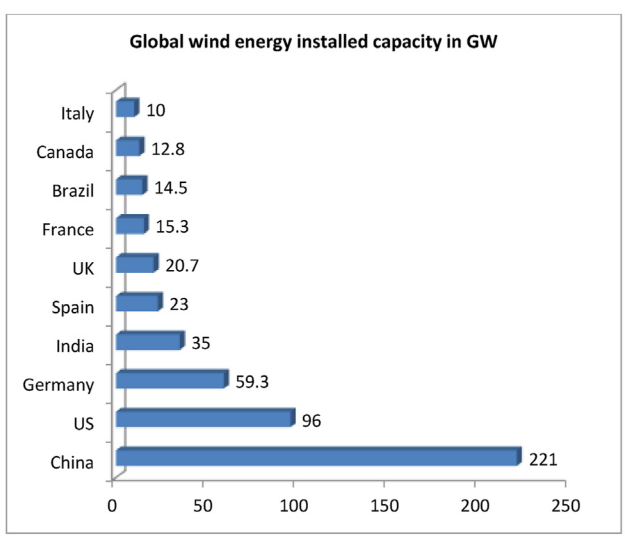
(b): Source: EIA, (2012)





(c) Source: OECD/FAO (2016)

(d) Source: OECD/FAO(2016)



(e) Source: OECD/FAO (2016)

Figure 3. The global renewable energy potentials: (a) cumulative annual PV installations. (b) global hydropower potentials, (c) global biodiesel production capacity, (d) 2019 global fuel ethanol production (e) 2019 world top 10 countries in wind energy capacity.

2010). Biodiesel has an overall higher efficiency than electricity and high energy density than electricity in electric vehicles and batteries in electric vehicles. Micro algae has the highest oil yield among most of the biodiesel feedstock and requires very less land compared to any feedstock for biodiesel. Hence, it does not compete with food (Taylor et al., 2013). Taylor et al. (2013) has proven that within a typical economic scaling factor of 0.8, an algal biodiesel process with an annual production rate of 100 Mt/year would achieve a biodiesel price

Table 13. Global biofuels consumptions by scenario in million tonnes (Ajavomnic and Hass 2010).

	2004	2007	2010 (RS)	2010 (AS)	2030 (RS)	2030 (AS)
WEO 2006						
USA	7	-	149	16	23	43
Brazil	6	-	8.3	9	20	23
EU	2	-	14.8	16	26	36
World	16	-	41.5	49	92	147
WEO 2009						
USA	-	15	-	-	44	Ca 65
Brazil	-	8	-	-	26	Ca 40
EU	-	8	-	-	26	Ca 36
World	-	34	-	-	133	278

comparable to the current conventional diesel price with a discounted break even time of 6 years.

4.2.1.2. Bio-ethanol potentials. Considering bio-ethanol as another source of renewable energy that undergoes combustion to generate energy and power, its advantages are enormous. These are listed below (Masum et al., 2013).

1. Ethanol is renewable fuel.
2. It is less toxic than gasoline.
3. It is an oxygenated fuel and promotes engine performance.
4. It burns with significantly reduced greenhouse gas emissions.
5. It has higher latent heat which increases volumetric efficiency.
6. It has high octane number, high laminar flame propagation speed.
7. It increases thermal efficiency and engine torque output.
8. It is cheaply produced.
9. It has lower vapour pressure which reduces the evaporation emissions.
10. It could be used in high compression ratio injection gasoline engine without knocking.

The world would need not less than 2 trillion litres of ethanol to replace the present gasoline consumption in the entire world (Lius et al., 2003). This requires about 400 million hectares of land. Currently bioethanol is produced using sugar cane in Brazil, corn in USA and China, and beets in the EU and China. Also, the use of lignocellulosic materials for bioethanol is developing in a very high significant rate while enzymatic hydrolysis will be commercially available in few years to come. Nearly 60% of energy matrix in Brazil is composed of renewable energy (Hydro-40%, wood and charcoal – 10%, sugar cane – 10%). CDM projects have been suggested as important alternative to trade for Brazil and other developing countries to ensure sustainable development and overcome heavy taxes from USA and EU. A UK –based life cycle assessment (LCA) on bioethanol production from wheat straw using current and emerging pre-treatment technologies has proven that stream explosion ethanol pathway remains environmentally favourable over petrol (Wang et al., 2013). Although there is obvious challenges of feedstock for bioethanol production due to fuel versus food crises and land availability and development, to date bioethanol policies have been proposed in sub-Saharan regions such as Nigeria, Mozambique, Uganda, South Africa, Malawi and Ghana. Mozambique has adopted policies of 50–10% of bioethanol with gasoline and South Africa suggested 400 million litres (20–50%) of biofuels by 2013. The biofuel association of Zambia (BAZ) has initiated biofuel introduction into existing energy policies and research into the use of sweet sorghum with sugar cane for bioethanol production. Very importantly, there is a growing association between EU and SSA. Underutilized lands in SSA are acquired by EU to grow bioethanol crops. The agreement benefits both parties where EU can reduce the use of fossil fuels by 20% by 2020 and SSA will gain international investment. The SSA can achieve bioethanol sustainability and some percentage of the biofuel feedstocks grown in SSA should be solely used in SSA.

Also, Masum et al. (2013), has extremely reviewed and reported on the reduction of combustion emission during the application of ethanol in different blends with gasoline in different gasoline engines (Table 17). It is clearly observed that there is an average reduction in pollutant emissions through the application of bio-ethanol. The sub-Saharan Africa has been identified as a place with low energy demand but high potential to meet global biofuel demand due to

Table 14. Percentage energy mix of electricity supplies some countries in 2019 (Jin and Kiu, 2020).

S/N	Country	Biomass	Coal	Nuclear	Gas	Hydro	Others	solar	wind
1	India	-	74.54	2.76	3.63	9.83	9.24	-	-
2	China	-	68.87	4.76	-	17.77	-	3.06	5.54
3	Germany	8.73%	30.06	13.71	10.23	3.74	-	8.98	24.56

Table 15. Selected country biofuels policy development in SSA (Jumbe and Mkondiwa, 2013).

SSA countries	Presence of policies	Biofuels mandates
Ghana	Energy policy, renewable energy	None
Angola	Biofuels law	None
Mozambique	Renewable energy policy, biofuels strategy	Blend mandate approved but not yet specified
Nigeria	Energy policy, biofuels strategy	10% ethanol target, no mandate
South Africa	Energy policy, renewable energy white paper, biofuels industrial strategy	Biofuels strategy approved in 2007 proposed 2 percent biodiesel and 8 percentage ethanol blend by 2013
Tanzania	Energy policy, in the process of developing a biofuels strategy	None
Zambia	Renewable energy, and biofuels industrial strategy	None
Zimbabwe	Draft energy policy	None
Uganda	Energy policy	None
Benin	Could not establish but has Agricultural revival programme	None
Mali	Renewable energy, and biofuels industrial strategy	None
Malawi	Malawi's national energy policy	Mandates 10 percent ethanol dependent on availability
Senegal	Energy policy	None
Mauritius	Multi-Annual Adaptation Strategy, Ethanol Development strategy	None
Swaziland	National energy policy-Renewable Energy Action Plan	None

Table 16. Biodiesel engine performance, combustion and emission condition.

Biodiesel feedstock		Engine	Operating Condition	Emission Results	References
Mustard oil methyl ester	BD MY	Horizontal, 1-cylinder, 4-stroke, AC, DI 1-Cylinder, 4-stroke, WC, RP: 5HP, RS: 1500 rpm	2200 rpm and 1 kg load is used. At different engine load and fuel blend	Lower all HC, PM, NO_X emissions with fuel blend Decreases HC, CO_2, emission with an increase in fuel blend and increase in NO_x	Bannikov and Vasilev (2012)
Cotton seed oil methyl ester	BD MY	1-Cylinder, WC, NA, 4 stroke, DI 1-cylider, 4S, DI, NA, D: 553 cm^3, RP: 4.476 kW, RS: 1800 rpm	1100–1800 rpm Different speeds and different blends 9 (B10, B20, B30) 1000–1600 rpm and full load	CO, PM, Smoke emission reduced, NO_x increased 10% increase in NO_x and lower CO, 24%PM, 14% smoke compare with diesel fuel.	Nabi et al. (2009); Hazar (2010)
Jatropha oil methyl ester	BD MY	1-Cylinder, WC, NA, 4 stroke, DI 1-Cylinder, 4S, WC, DI, RP: 8,82 kw, CR: 17:1, RS: 2000 rpm	Different speeds (1500 and 2000 rpm) and different load	Lower smoke, CO, HC and NO_x Decrease CO, HC and NO_x with increase in engine speed	Nabi et al. (2009); Huang et al. (2010)
Karanja oil methyl ester	BD MY	1-Cylinder, WC, NA, 4 stroke, DI 3 Cylinder, AVL make CI engine, CR: 18.1, WC, RS: 2200 rpm, P:44.1 kw	1200 rpm Full throttle at 1200 rpm, 1400 rpm and 2200 rpm and 20%, 50% and 100% blends	Lower smoke, CO. Engine noise emission and higher oxygen, combustion efficiency, NO_x Slightly increased CO, NO_x and reduce HC, PM and smoke with an increase in blending ratio	Nabi et al. (2009)
Coconut oil methyl ester	BD MY	1-Cylinder, 4 stroke, AC, DI 1-Cylinder, 4 stroke, WC, NA, DI D: 638 cm^3, RP: 8.8 kw, RS: 2400 rpm.	2600 rpm A full load varying speed condition	PM, Soot, CO, decrease and NO_x increase Reduces CO, HC emissions and higher NO_x emission	Hossain et al. (2012); Habibullah et al. (2014)
Soy based biodiesel	BD MY	1-Cylinder, 4 stroke, WC, DI 1-Cylinder, 4 stroke, DI, CR: 16.5:1, RP: 11.03 kw, RS: 2000 rpm	1800 rpm under various load At full load and different engine speed	CO, PM decrease and NO_x BSFC increase Decrease CO, HC, NO_x and smoke by 27, 27, 5, 52% respectively	
Linseed oil methyl ester	BD MY	1-Cylinder, WC, NA, 4 stroke, DI 1-Cylinder, 4S, DI, RP: 4.4 kw, CR: 17.5:1, RS: 1500 rpm	1000 rpm At different loads, constant speed and different injection pressure	PM, CO, smoke lower and NO_x higher Decrease CO, HC and smoke emission but increase in NO_x	NabiMd and Najmul (2008); Puhan et al. (2009)
Neem oil methyl ester	BD MY	1-Cylinder, WC, NA, 4 stroke, DI 1-Cylinder, AC, DI, CR: 17.5:1, RP: 4.4 kw, RS: 1500 r; pm	Various load At different blends, constant speed and different break power	NO_x, CO. HC and smoke reduced Lower CO, HC but increase NO_x and smoke emission with increase in fuel blend and engine load	Elango and Senthilkumar (2010)

AC-air cooled, WC-water cooled, NA-natural aspirates, DI-direct injection, TC-turbocharged, PM-particulate matter.

availability of vast arable land and clement climatic conditions. There are obvious low biofuel mandates and targets in the region and strong government and private sector involvement in the biofuel policy developments (Jumbe and Mkondiwa, 2013). This will help to build trust, collective responsibility and combined risk management to succeed in having shared outcomes for investors, farmers and the environment. France is already producing bioethanol from plants containing sucrose and the ethanol is added as fuels either in pure form or as ETBE (45% ethanol + 55% isobutylene). The Swedish foundation for the development of ethanol has existed for over 30 years ago and by 2020 had 15% of its transportation fleet using fuels from biomass and currently producing ethanol from paper and forest residues. China has increased ethanol share in gasoline to 10% with over 4 billion litres of ethanol as annual production. USA has taken several investment projects there to produce ethanol from corn. Japan is also developing very important program to add ethanol to diesel and has formed alliance with Canada, Australia, Thailand and Guatemala with trade of fuel ethanol as objective (Lius et al., 2003). Also, other countries such as Argentina, Colombia, India and Mexico among others are introducing smaller scale ethanol programs. From Table 17, about 22 different engines were tested, only 5 showed increase in NOx emission, only four (4) showed increase in HC and only one (1) showed increase in CO_2. Also, three (3) out of the five (5) that showed increase in NOx emission equally recorded lower NOx emissions in varying condition and two (2) out of the four (4) that showed increase in HC recorded decrease in HC emissions when the engine operation conditions was changed. It implies that Table 10, shows significant result of decrease in emission on bio-ethanol application in combustion engine.

4.2.1.3. Biogas potentials. The biogas as another potential biofuel source has high octane rating and calorific value (4700–6000 kcel) and it can be used in lamps and 1 Kwh of electricity can be generated from 0.7 m^3 of biogas which can light 60 W electric bulb for 1 h (Muhammad and Zakariya, 2013). Also, possible option to reduce the amount of electricity consumption for refrigeration purposes is by applying biogas-powered novel absorption –refrigeration cycle. Approximately 0.044 m^3 of biogas consumption would generate 230 kW capacity. There are over 27 million biogas plants in China and 4 million in India (Bond and Templeton, 2011). Ten years ago, the UN announced the global alliance for clean cook stoves which had the target of delivering 100 million clean cook stoves by 2020. It is reported that 1500–2400 L of biogas is sufficient to supply cooking requirements for a family of five. It has the advantages of highly reduced NOx and GHG emissions as well as improved air quality. It does not compete with food since it is generated from waste products. It has been reported that up to 0.5 $gigam^3$ of biogas could be produced daily in Kilimanjaro region of Tanzania. This exceeds by far the 0.72 million m^3 required for cooking in the region while 3.0 MWh energy required for small economic activity in the region is about 0.15 of the total energy that can be generated from agro waste materials (Mkiramweni, 2012). Also, Ahmmad and Haque (2014) has estimated the potentiality to generate electricity as 207.288, 873.034 and 2878.134 MW/day in 2020, 2025 and 2050 using municipal solid waste in Dhaka City of Bangladesh.

Table 17. Bio-ethanol engine performance, combustion and emission condition (Masum et al., 2013).

Engine	Ethanol concentration in blend	Adjustment and/or modification and test condition	Emissions impact
4S, 1C CR: 6/10–10/1, EIS	0%, 25%, 50%, 75%, 100%	CR 6:1 and 10:1 Varying speed (1500–4000 rpm)	E↑ and NOx↓, CO, HC, CO_2↓
4S, 1C CR: 5/1–13/1	0%, 50%, 85%	CR 10:1 and 11:1 Varying speed (1000–5500 rpm)	E↑ and NOx ↓, CO, HC↓ BSFC↑
4S, 4C, MIS, WC	0%, 5%, 10%	WP = 5–20 kw speed = 80 and 100 km/h	80 km/h: 11% and 15.5% NOx↓ 100 km/h: 10.55 and 13.55 NOx↓
1C, 4S, AC, EDI + GPI, CR 9.8/1	0%, 24.3%, 48.4%, 60.1%	Speed = 3500–5000 rpm	E < 24.35 NOx↑ E ˃24.3% NOx↓, HC↑, CO↑
4S, motorcycle, carburetted engine (CE) and fuel injected engine (FIE)	0%, 15%	Constant speed	CE 36% NOx↓ FIE 3% NOx↑, CE HC and CO↓ FIE HC and CO↓
1C, SI, CR 10.5/1	0%, 10%, 20%, 30%, 40% and H10%, 20%, 30%, 40%	Constant speed (2000 rpm)	NOx↓, HC and CO↓
1C, AC, CR 8.5/1	0%, 100%	Speed: 1600–3600 rpm	NOx↓, CO, HC↓, CO_2↑
1C, GPI, CR 9.5	0%, 25%, 50%, 75%, 100%	IMEP = 3 and 5 bar	NOx↓, HC↓
4C, FFEPFI, CR 10.35/1	25% and H 30%, 50%, 80%, 100%	Load = 60 and 105 Nm	At 60 Nm NOx↓ at 105 Nm NOx↑, At 60 Nm HC↓ at 105 Nm CO↓ HC↓
1C, DISI, CR 9.5	0%, 5%, 25%, 85%, 100%	Constant Speed (2000 rpm)	E<25% NOx↑ E˃25% NOx↓
4C, MIS, WC, CR 10.4/1	0%, 5%, 15%	Wheel power 5–20 Kw Speed 80 km/h	E5: 11% NOx↓ E10 15:5% NOx↓, CO, HC↓
MFIE, CR 9.8/1	0%, 5%, 10%, 20%, 30%, 40%	Cold start condition, intake air temperature 20 °C	E5, E10 NOx↓ E10 15.5% NOx↓, E5, E10 CO, HC↑ E˃ 10%, CO, HC↓
4C, SI	0%, 10%, 25%, 50%, 85%	Constant engine speed	NOx↓, CO, HC↓
1C, SI, AC, CR 11.3/1	0%, 5%, 10%, 15%	Idle, 2500, 5000, 6500 rpm	NOx↓
DISI, turbocharged	0%, 10%, 20%		NOx↓
DISI, CR 12/1	0%, 25%, 50%, 85%	End of injection CAD 45-5 BTDC	NOx↓, HC↑, smoke↓
4C, SI, CR 12/1	22%, H100%	Engine speed 2500–6000 rpm	NOx↑ (compared with E22), HC & CO↓
1C, CR 10.5/1	0%, 6%, 10%, 15%, 20%	Speed 2000 rpm	NOx↓ (except E6), HC↑ & CO↓
DI, CR 11.5/1	0%, 10%, 20%, 30%, 50%, 85%, 100	Speed 1500 rpm IMEP = 3.4 bar	NOx↓, CO, HC↓
1C, CR: variable	0%, 5%, 10%, 15%, 20%, 25%, 30%	Speed: 1500 rpm CR: 8 and HUCR	NOx↓, CO, HC↓
4C, CR 9.7/1	0%, 5%, 10%, 15%, 20%	Speed: 1000–5000 rpm	NOx↑, HC & CO↓
4C, CR 10.5	0%, 85%, 100%	Speed: 3500 rpm	NOx↓, CO, HC↓

EIS- electronic injection system, EDM-ethanol fuel direct injection, GPI- gasoline port injection, C- cylinder, CR-compression ratio, MIS- multi-point injection system, WC- water cooled, AC- air cooled, FFE-flex fuel engine, MFIE-multi-point fuel injection engine, HUCR-high useful compression ratio, E-ethanol, Hxx%- xx%hydrous ethanol in gasoline, ↓- decrease, ↑↑- increase compared with E25.

5. The impacts of biofuels and remedies

5.1. Impact on soil

Biomass crops challenges good soil management and poses risk of growing pressure on biodiversity. This can be controlled by using perennial crops to reduce soil disturbance, greater soil cover, and lower soil erosion and improve soil organic matter and increase biodiversity.

5.2. Impact on water

There may be negative impacts by introducing energy crops on regional or local hydrology and discharge of effluents and in-filtration of herbicides, fertilizers and insecticides. The use of perennial crops and non-tiller buffer zones will help to reduce the COD and BOD levels in water courses.

5.3. Impact on the environmental

There are obvious environmental cost implications on local water and air quality due to reforming, transportation and combustion process of biofuels which equally grow significantly to meet the rapidly increasing global demand. Increasing efficiencies in water and energy use at efficiencies can go a long way in curbing the air and water pollution. Also, promoting the establishment of small-scaled facilities will aid communities to control and manage waste. The combustion biofuels and their blends with fossil fuels result in more local emissions of HC, CO, SOx and particulate matter than fossil fuels. Also, there is a serious concern about the level of NOx and VOC emissions from biofuels. However, improvements in vehicles and change in fuel blends and additives, improved fuel pre-treatment processes, and next generation biofuels will provide major contributions to reducing air pollution in transport sector. Several groups are in top gear of developing additives to address the issue of NOx, emissions associated with biodiesel blends (Ronald, 2006).

6. Conclusion

The COVID-19 pandemic has had serious impact on the world health but much more on the economy, education, sports, religion and security. It is however, the COVID-19 pandemic lockdown on the environment that has positively impacted the world. The concern for the environment has been palpable because it is one single phenomenon that affects all spectrums of the society. Targets have been set at international conferences with representation at the highest levels of government around the world for environmental cleanliness with commitment from most of the countries. Unfortunately, these targets are not met by countries for factors that border on economic, security, politics and international diplomacy. Hence the world, particularly the developing countries continue to reel under the weight of environmental degradation. COVID-19 pandemic and the consequent lock down concomitants that have constricted human socio-economic activities has in the process engendered environment serenity and stability albeit fortuitously. It is therefore important that government leverage on the positives derivable from COVID-19 pandemic environment into post COVID-19 era. This can be done through sustainable renewable energy policy measures.

7. Recommendations and policy implications

- COVID-19 pandemic has provided opportunities for a clean environment thereby achieving what the nations have not been able to achieve for the environment. Capitalising on these positives requires the following; In the first place, there is need for a master plan from the government for renewable energy. The master plan will be a result of consultations from stakeholders that will include experts, political office holders and Community Development Committees (CDC) as well as religious and business leaders.

- Governments should take steps to reduce emphasis on fossil fuel as a source of electric energy because of its environmental degradation impact. One way of doing this is through a thorough review of energy policy in the country that will make investment in the renewable energy a priority. This can also be achieved through the immediate abrogation of gas flaring in the countries where the practice still takes place.
- This is an opportunity to diversify economy away from oil and boost agriculture and support transport system that are environmental friendly. This will help reduce pollutant emissions, improve health, create jobs and provide other environmental and other economic benefits.
- COVID-19 pandemic has become a wakeup call to do things differently. Let everybody ensure that lessons from the crises of COVID-19 pandemic are learned and the positives as they concern the environment jealously guarded and implemented.
- In as much as renewable energy resources are advocated, for due to its numerous benefits, efforts should be made to ensure that their integration into the energy base is gradually carried out and not a transition revolution. Consideration should be given to ensure that:
  - o The incompatibility of wind and crop farming are carefully addressed.
  - o Life cycle analyses (LCA) are conducted on each biofuel feedstock application.
  - o Hydropower challenges of dam-causing-distress on the downstream countries.
  - o The increase in O_3 levels in some cities like Valencia during the lockdown has been attributed to rainy and cloudy conditions (AEMET, 2020). Conditions that limit VOCs emission have been advocated to reduce O_3 formation and a reduction ratio of VOCs to NOx concentration should be maintained lower than 0.73 (Zeng et al., 2018). Also, more attention on home cleaning, fireplaces and garden activities could have equally promoted the increase in O_3 (Wolff et al., 2013). Therefore, the above activities and other related precursors to O_3 generation should be under serious check.
- Building of large scale and distributed energy storage infrastructure would ensure the common challenge of instability of solar and wind energy resource.
- The application of artificial intelligence (AI) is recommended to handle infrastructure and equipment management, load forecasting and generation forecasting in energy sector. The possibilities and immense result achieved during the pandemic and future application has been reported (Jin and Kiu, 2020). AI can be applied in handling fault detection and proactive measures for emergency repairs as well as significant long term, medium and short-term load forecasting would help for efficient and effective planning, operations and maintenance schedules. It has been successfully implemented in China and other nation could equally follow suit. AI can be very useful in handling stability and security challenges associated with solar and wind energy (Hassan et al., 2019).

Declarations

Author contribution statement

Eyisi Rita, Esonye Chizoo & Ume Sunday Cyril: Conceived and designed the analysis; Analyzed and interpreted the data; Contributed analysis tools or data; Wrote the paper.

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