International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2025, 15(1), 456-465.

Clean Energy Consumption and Human Welfare in Nigeria: Implication for the Sustainable Development Goal 7

Misery M. Sikwela, Timothy A. Aderemi*

Department of Public Administration and Economics, Mangosuthu University of Technology, Durban, South Africa.
*Email: aderemi.timothy@mut.ac.za

Received: 01 November 2024 **Accepted:** 08 December 2024 **DOI:** https://doi.org/10.32479/ijeep.18077

ABSTRACT

Over the time, in driving human welfare in Nigeria, the country has been consuming little clean energy relative to other sub-Saharan African nations. This has raised a critical concern for the policymakers and scholars in the recent times. As such, this study estimated the relationship between clean energy consumption and human welfare in Nigeria from the period of 2000 to 2020, this study employed a Dynamic Ordinary Least Squares, with the following conclusions emanated from the study. Clean energy consumption and human welfare had an insignificant negative relationship in Nigeria. Health expenditure and human welfare had a significant negative relationship. Population growth and human welfare had a significant inverse relationship in Nigeria. However, standard of living contributed a positive and significant contribution to human welfare in Nigeria. By and large, clean energy consumption did not contribute to an improvement in human welfare in Nigeria. In the light of the above, this study recommends that whenever the policymakers in Nigeria wish to achieve some substantial level of human welfare in the country, policies that will drive affordable clean energy SDG-7 in the country should be embarked upon.

Keywords: Clean Energy, Human Welfare, Life Expectancy, Sustainable Development Goals 7
JEL Classifications: C23, Q42, Q43, Q56

1. INTRODUCTION

1.1. Background

According to the UNDP (2015), energy shortage is one of the major barriers to meeting the Sustainable Development Goals (SDGs) by 2030. The inability of impoverished people to access basic energy services stifles human development, keeping them in a cycle of poverty (Karekezi et al., 2012). The United Nations Conference on Trade and Development (UNCTAD, 2017) endorses this viewpoint, emphasising the importance of access to energy services, particularly contemporary ones, in reducing poverty, generating jobs, improving the economy, providing social services, and furthering human development.

Energy poverty is defined as a lack or difficulty in acquiring contemporary, dependable energy services, notably electricity and clean cooking fuels. Insufficient energy availability harms the environment and impedes socioeconomic growth (Juliette and Willy, 2021; Asiegbu et al., 2023). According to research, sub-Saharan African countries do not have appropriate access to modern energy sources. Africa suffers substantially more from energy poverty than other regions. Despite the continent's rich renewable and non-renewable energy resources, which may cover its demands for the next century, most African countries experience energy poverty as a result of low real incomes and economic underdevelopment. While contemporary energy sources are typically more ecologically benign than traditional ones, the majority of Africans continue to use traditional energy sources, with just a tiny percentage having access to modern energy (World Bank, 2021).

Human welfare, which includes quality of life, health, and education, is inextricably related to energy availability. Energy usage, poverty, ethnic strife, currency rate changes, and the quality of public healthcare are just a few of the elements that affect human welfare in Nigeria. Notably, energy availability influences human welfare and health (Omonona and Ajiboye, 2011). The United Nations' SDGs contain a particular objective (SDG 7) aimed at achieving sustainable energy by increasing the percentage of renewable energy in the global energy mix, maintaining an adequate energy supply, and improving global access to clean energy (United Nations, 2015).

Human capital, defined as a population's knowledge, abilities, and experience, is also linked to economic growth and welfare (Aydin and Demiroz, 2023). According to Istekli and Serdengeçti (2021) and Shahbaz et al. (2021), income generation is a key indication of society welfare. Health and education, as essential kinds of human capital, are required to boost human production (Li and Huang, 2009). The usage of fossil fuels such as coal, gas, and crude oil harms both the environment and human health (Ikpeze et al., 2015). However, using energy-efficient equipment and energy-saving techniques can increase energy access, availability, and quality of life, hence improving human well-being (Umoh and Bande, 2021). According to research conducted in Nigeria, there is a positive and substantial association between life expectancy and energy sustainability. Furthermore, air pollution caused by fossil fuel use endangers health (Boggio-Marzet et al., 2021), and vehicle fuel usage exacerbates environmental and health problems (Zhao et al., 2018). Renewable energy sources such as solar, wind, and hydropower have little influence on the environment and can improve human welfare.

1.2. Statement of the Research Problem

A significant portion of Nigeria's population lacks access to modern energy sources, which presents a critical issue for the nation's development. According to the National Bureau of Statistics, more than half of Nigeria's population is multidimensionally destitute, using dung, wood, or charcoal for cooking instead of cleaner energy sources (NBS, 2022). Nigeria has long suffered severe energy issues (Dimnwobi et al., 2022). The country relies significantly on inefficient and polluting energy sources, and despite recent advancements in the power industry, Nigeria continues to have insufficient power supply (Gershon and Emekalam, 2021). Nigeria consumes less electricity per capita than other Sub-Saharan African countries. However, Nigeria has a plethora of renewable energy resources, such as biomass, solar, wind, and hydro, which are mainly undeveloped (Dimnwobi et al., 2022).

The use of clean energy in Nigeria has the potential to dramatically improve human wellbeing. Nigeria has a huge and quickly rising population, resulting in increased energy consumption. However, the country's energy industry continues to rely heavily on fossil fuels, which have negative consequences for both the environment and human health. Transitioning to sustainable energy sources such as hydroelectric, wind, and solar power might offset these negative effects and improve human welfare in a variety of ways. The advantages of clean energy adoption include improved air quality and pollution reduction, better health outcomes for Nigerians, expanded access to electricity, job development in the renewable energy industry, and mitigating the negative effects of climate change on human welfare. Furthermore, increasing the usage of renewable energy sources could help Nigeria achieve sustainable domestic energy demands.

Nigeria is aggressively attempting to diversify its energy mix and minimise its dependency on fossil fuels, making the use of clean energy an increasingly significant issue. Despite possessing rich renewable energy resources like as hydropower, biomass, sun, and wind, the country now gets just around 18% of its electricity from clean sources.

New study demonstrates renewable energy's potential to boost human welfare. According to a World Health Organisation assessment (WHO, 2022), air pollution from fossil fuels causes around 6.7 million deaths per year. Clean energy sources may greatly improve human health by lowering air pollution. Although Nigeria's use of clean energy is still relatively low, many Nigerian families are beginning to install solar-powered lighting and invest in renewable energy technology. In light of these concerns, the purpose of this study is to investigate the link between clean energy use and human welfare in Nigeria.

1.3. Significance of the Study

In Nigeria's pursuit of the UN Sustainable Development Goals (SDGs), notably SDG 7-access to affordable, reliable, sustainable, and modern energy for all-this study is vital. Addressing energy poverty in Nigeria is critical to breaking the cycle of poverty, improving health outcomes, and promoting economic development. This study gives insights into the relationship between clean energy utilisation and human welfare, which may be used to drive policies and activities targeted at increasing access to contemporary energy services. Such access is critical for improving quality of life, increasing productivity, and fostering sustainable development throughout the country.

Furthermore, the study's findings may aid Nigeria's efforts to vary its energy mix and minimise dependency on fossil fuels. Making the switch to renewable energy such as wind, hydropower and solar can help to offset the harm to the environment and health risks linked with fossil fuel consumption. Adoption of clean energy technologies can also boost job development, improve energy security, and strengthen the nation's commitment to tackling climate change. Finally, this study emphasises the relevance of sustainable energy solutions in enhancing human welfare and meeting long-term development goals in Nigeria.

2. LITERATURE REVIEW

It is imperative to review major concepts and empirical findings concerning clean energy and welfare in Nigeria. This section will cover these essential aspects, offering a thorough grasp of the nexus between clean energy consumption and human welfare in the Nigerian environment.

2.1. Energy Consumption in Nigeria

The phrase "energy consumption" deals with the amount of energy utilised for diverse purposes, like machine operation, lighting and cooking. Individuals as well as families utilise many energy sources. These sources are divided into two categories: traditional and modern. Modern energy sources are highly complicated, whereas ancient energy sources are antiquated and basic. Low-tech sources are the basis of conventional sources. Conventional energy sources include charcoal, agricultural residue, firewood, sawdust, and animal waste (World Bank, 2021). Conversely, contemporary energy sources rely on cutting-edge technology. Contemporary energy sources include gas, kerosene as well as electricity (Ogwumike and Ozughalu, 2012; Sher et al., 2014; World Bank, 2021).

The energy consumption situation in Nigeria is a source of worry owing to insufficient and dirty energy usage, as well as a substantial number of individuals who lack access to electricity. Nigeria's per capita electric power usage is 144 kWh, which is low when compared to other nations in Sub-Saharan Africa. The country seldom meets 33% of its energy requirements with hydropower and natural gas making up the majority of the energy mix, resulting in environmental implications (Dimnwobi et al., 2022).

In Nigeria, where the usage of unconventional energy sources together with inefficient cooking methods has resulted in major environmental and health problems, clean energy consumption is critical to human health (Okunola and Olagunju, 2019). The Sustainable Development Goal (SDG 7) encourages the use of greener energy sources (Akindele-Sotunbo et al., 2022). Fuel wood is frequently used for heating and cooking, however it poses health problems due to its poor combustion (Okunola and Olagunju, 2019). The type of cooking energy utilised in Nigerian homes is mostly dictated by economic success; lower-class families use wood, while upper-class households use modern fuels (Bello, 2011). According to Kadafa et al. (2017), an overreliance on fuel wood poses a substantial risk to forestry ecosystems, resulting in a variety of environmental issues like deforestation, climate change, erosion, and floods.

2.2. Sustainable Development and Human Welfare

The Brundtland study, conducted by the United Nations World Commission on Environment and Development in 1987, popularized the notion of sustainable development. The report defines sustainable development as meeting current demands without compromising future generations' ability to meet their own needs. According to Ogwumike and Ozughalu (2015), sustainable development prioritizes future generations' well-being. According to Todaro and Smith (2011), it refers to a growth pattern that will allow future generations to live at least as well as the current one.

The Sustainable Development Goals (SDGs) are a series of 17 objectives designed to address many areas of human welfare, such as economic development, environmental stewardship, and social fairness (De Neve and Sachs, 2020). The SDGs are a critical but difficult set of goals for countries to enhance the well-being of their citizens. The SDGs are connected to the: determinants of well-being," such as social support, income, freedom, generosity, health and faith in government, and there exists an substantial association between attaining sustainable development and self-reported measures of well-being. (World Happiness Report, 2020).

When analysing sustainable development, environmental quality is an important issue to consider. As a result, sustainable development excludes any development that has an adverse effect on the environment. To develop sustainable energy, all people must possess the ability to get affordable energy services, adequate to fulfil basic requirements, eco-friendly and well-liked by both people and communities. This necessitates delivering sustainable energy services (Haberl, 2006; Lior, 2008). According to research, to achieve sustainable growth, the energy sector must strike a balance between social and economic advancement and environmental preservation. (Ayres et al., 2007).

2.3. Growth and Development Theory

The study of the elements that lead to economic growth and development is known as growth and development theory in economics. It implies that through lowering energy costs, enhancing energy security, and generating new employment opportunities in the clean energy industry, clean energy can contribute to economic growth.

The idea of sustainable development, or development that meets current needs without endangering the capacity of coming generations to meet their own, is one of the central ideas of growth and development theory.

The generation of clean energy comes from sustainable and renewable resources including wind, solar, and hydroelectric power. Its advantages include lowering pollution, enhancing air quality, and lessening the effects of climate change. Reduced incidences of respiratory illnesses, heart disease, and cancer are but a few of the health advantages that can result from improved air quality brought about by clean energy. Reduced heat stress and fewer extreme weather events are only two of the health benefits that clean energy can help to prevent. Climate change can also lead to other benefits. Furthermore, there exist other indirect impacts of renewable energy on human health.

Clean energy, for instance, can boost the economy and create jobs, which can facilitate better access to social services like healthcare. It can also aid in the reduction of poverty, which is a significant risk factor for several illnesses.

2.4. Energy Poverty Theory

The origins and effects of energy poverty are examined by energy poverty theory. According to some specialists, energy poverty is the absence of access to modern, sustainable energy commodities and services (Falak et al., 2014). According to this definition or conceptualization, people who rely solely on conventional energy sources to meet their needs can be categorized as energy poor.

According to the theory of energy poverty, clean energy can lessen energy poverty by increasing how accessible and inexpensive energy is.

The idea of energy poverty enables us to comprehend why low-income and marginalized populations are disproportionately affected by air pollution. Solid fuels like wood, coal, and charcoal are frequently used more frequently by those who are energy poor for cooking and heating. These fuels release dangerous toxins that can lead to cancer, heart disease, and respiratory infections, among other health issues.

We can create more equal and successful sustainable energy policies with the aid of the energy poverty theory. For instance, laws that lower the cost of renewable energy for low-income households can both lower energy poverty and enhance public health.

One of the main causes of stress in households can be energy poverty. Stress levels might drop and general wellbeing can be enhanced with access to dependable and reasonably priced clean energy.

India's rural villages now have improved access to healthcare and education thanks to solar-powered microgrids that provide electricity (Swarooprani, 2023). Communities in Kenya are receiving clean water via solar-powered water pumps, which is assisting in the containment of the spread of waterborne illnesses (Bwire, 2019). To lower air pollution and enhance public health, the Chinese government is making significant investments in clean energy technology, like the use of electric cars and renewable energy power plants.

2.5. Public Health Theory

This theory investigates the variables affecting public health. It implies that by lowering air pollution and expanding access to clean water, clean energy can improve public health. A wide range of academic fields are included in the vast field of public health theory, including epidemiology, behavioural and social sciences, health policy and environmental health. Its goals are to comprehend population health and make improvements to it (Li et al., 2022a; Li et al., 2022b). One of the main tenets of public health theory is that whole physical, mental, and social well-being is the condition of health rather than only the absence of sickness.

This holistic approach to health acknowledges that a variety of variables, including social determinants of health like housing, income, and education, can affect the health of a person or a society. As stated in the seventh Sustainable Development Goal (SDG 7), cheap, sustainable, and clean energy access is essential to achieving SDG 3 (health) (WHO, 2022).

By lowering the emissions of dangerous pollutants including sulfur dioxide, nitrogen oxides, and particulate matter, clean energy can enhance the quality of the air. Inhalation of these contaminants can cause lung cancer, heart disease, asthma, and other health issues. The extraction and burning of fossil fuels can contaminate water and soil; clean energy can lessen this impact.

By doing this, people may be shielded from exposure to harmful substances that may result in cancer, birth defects, and other health issues.

Furthermore, the effects of climate change can be lessened by the use of renewable energy. Since rising sea levels, more extreme weather events, and the spread of infectious illnesses are all predicted effects of climate change, it poses a serious threat to public health.

Additionally, as clean energy investments can strengthen local economies and create jobs, they can improve the health and well-being of both individuals and communities. These benefits can be seen in the reduction of social determinants of health.

2.6. Review of Empirical Literature

A lot of research has shown how important energy is for both economic growth and human development. For example, Hulten et al. (2006) discovered that increases in energy production capacity had a favourable effect on economic development and productivity. Similarly, Sari and Soytas (2007) looked at six developing countries and found that energy was a big factor in how productive they were. Panel data from 130 countries were used by Alaali et al. (2015) to show that both energy use and human capital are important for economic growth. Pasternak (2000) also found a strong positive link between the Human Development Index (HDI) and the amount of energy used per person, which suggests a level of electricity use required for the highest HDI.

In 2006, Wolde-Rufael used the Granger causality test to look into the link between energy use and economic growth in 19 African countries. He found evidence for both long-term and short-term causality in different situations. Akinlo's (2008) multivariate causality tests in 11 African countries backed up these results. Chontanawat et al. (2008) pointed out that the link between economic growth and energy use is stronger in industrialised countries than in developing countries. Additionally, Martínez and Ebenhack (2008) and Aderemi et al. (2021) both discovered a link between energy use and HDI, with developing countries' social and economic conditions getting better when they had access to electricity.

Wolde-Rufael's 2009 study looked at the link between energy and economic growth in 17 African countries, adding capital and labour as variables. They found that energy was not the main factor that caused output growth, but capital and labour were. Additionally, Pirlogea (2012) discovered that in six European countries, both fossil fuels and renewable energies had positive effects on human development. Wang et al. (2018) and Tran et al. (2019) both looked at the link between using renewable energy and human development and found that it was n't a significant one in Pakistan or a group of 90 countries. Wang et al. (2020), on the other hand, found that renewable energy use is what propels human progress in BRICS nations.

Some environmental studies, like those by Hussain and Yu (2021) and Sasana and Aminata (2019), looked at how energy use affects economic growth and CO_2 emissions. They found that using renewable energy makes CO_2 emissions worse, while using fossil fuels makes emissions worse. Zou and Zhang (2020) showed that China's energy use and CO_2 emissions are linked in both directions, which shows how regional effects can spread. Adebayo's research in 2021, which looked at Japan, confirmed these results by finding links between economic growth, energy use, trade openness, and population growth.

A number of studies have also looked at how clean energy affects health. Juliette and Willy's research in 2021 showed that in sub-Saharan Africa, energy poverty did not have a big effect on CO_2 emissions, but primary energy use did. Twumasi et al. (2021) and Imran and Ozcatalbas (2020) talked about how clean cooking fuels are good for your health because they improve the quality of the air inside your home and lower the risk of respiratory illnesses. Life satisfaction and mental health are better when homes use renewable energy, according to Druica et al. (2019) and Akter and Pratap (2022). Liu et al. (2018) said that China's use of renewable energy made heart and lung diseases less likely. Dimnwobi et al. (2023) looked into the relationship between 35 SSA countries' agricultural productivity, environmental degradation, and energy shortage. The instrumental variable generalized approach to moment (IV-GMM) technique was applied to the aggregate SSA framework, while the IV-two stage least square approach was employed for the sub-regional examination of the Central, East, West, and South African blocs. The primary findings from the SSA framework demonstrated that, whereas greenhouse gas emissions significantly impacted agricultural output negatively, the measure of energy shortages significantly benefited the sector. However, because of regional variations in a thriving economy, regional variations in agricultural output, and regional disparities in available resources, the Central, East, West, and South African simulations yielded quite different results.

Using precise geographic data, Farthing et al. (2023) assessed the final electricity consumption for a range of farming productive uses of power in Sub-Saharan Africa. Using REopt, a technoeconomic optimization paradigm of energy systems, the cost and system scaling impacts of integrating farmed productive consumption of electricity into microgrid layouts in Kenya and Zambia were investigated. The study found that the maximum yearly power required for farming, grinding, bombing, cooling, and egg hatching in Sub-Saharan Africa was 16.8 TWh. It has been demonstrated that including profitable localized farming practices in microgrid system layouts increases the required system size without affecting the standardized price of power for these systems.

The relationship between agricultural productivity and global warming in industrialized and developing countries was investigated by Nugroho et al. in 2023. The study included data from 24 advanced and 71 emerging countries between 1990 and 2020. Using the three-stage least squares method, it was found that while farming productivity decreased in wealthier countries, it increased in emerging countries. Reduced farming production was the effect of climate change in both developed and developing countries. But the productivity of agricultural in developed countries was more sensitive to changes in temperature.

Tagwi (2023) examined how trade liberalization, greenhouse gas emissions, and the availability of green power in South Africa affected the country's agrarian economy between 1990 and 2021. A fully modified ordinary least square (FMOLS) test, an autoregressive distributed lag (ARDL) limits evaluation, a dynamic ordinary least square (DOLS) test, and a canonical cointegrating regression (CCR) econometric analysis were all used to analyze the association. The results showed that although commerce enhances the agricultural sector, agricultural development deteriorates ecological conditions. The scale of the green power source contributed to the farming sector's downturn.

Chidiebere-Mark et al. (2022) used panel data from the FAOSTAT and World Development Indicators databases, which cover 31 African countries, to investigate the relationship between African farming productivity, green power, FDI, and greenhouse emissions. The methodology used in the study was a panel autoregressive distributed lag model. The results showed that livestock output, fertilizer use, and net foreign direct investment significantly increased greenhouse gas emissions over the medium and long term. Using green power significantly decreased greenhouse gas emissions both over the long run and short term. The findings recommended significant adoption of climate-smart farming practices and environmentally conscious foreign direct investments in Africa. They also demanded funding for the creation and use of renewable energy.

The role of green electricity and biodiversity for agricultural sustainability in ASEAN countries was investigated by Chopra et al. in 2022. Using the Mean Group (MG) class estimators, it was discovered that environmental degradation reduces agricultural productivity in the region. Although the use of renewable energy sources increases crop yields, environmental variables and the amount of forest cover have a negative effect on industry productivity. Despite being one of the most connected regions in the world, the results showed that the ASEAN countries' agricultural output is not increased by globalization. The findings of bidirectional causality between agricultural output and the use of green power and unidirectional causality among a number of other variables were corroborated by the causality studies.

The relationship between economic development, agricultural value-added, and carbon emissions in the Visegrad Group countries was examined by Czyzewski and Michaowska (2022). Slovakia, Poland, Hungary, and the Czech Republic were all investigated between 2008 and 2019. The research, which covered the years 2008-2019, found a positive relationship between economic growth, carbon dioxide emissions, and agricultural value added. Slovakia was just exceeded by Hungary as the country with the lowest number of emissions, according to studies on the ecological effectiveness of carbon dioxide emissions in farming in terms of the gross added value generated.

Using data from 1960 to 2017 calculated by an annual rate, Sibanda and Ndlela (2022) examined the relationship between greenhouse gasses, crop output, and manufacturing production in South Africa. They generated a total of 58 yearly reports. Using the Autoregressive Distributed Lag method, the approach was bivariately evaluated. The information showed that industrial and agricultural output has minimal effect on greenhouse gas emissions. On the other hand, crop productivity is impacted by greenhouse gas emissions and manufacturing output. The results showed that food availability had been adversely affected by declining agricultural output brought on by global warming caused by carbon emissions.

Tagwi (2022) evaluated how South Africa's farming sector was affected by greenhouse gas pollution, environmental deterioration, and the use of green electricity between 1972 and 2021. The link was examined using an econometric technique known as the Auto Regressive-Distributed Lag (ARDL) Bounds test. The study's findings demonstrated that while environmental degradation slows agricultural economic growth, greenhouse gas pollution increases as agricultural productivity increases. Green power was used sparingly in the short and long durations. Granger's greenhouse gas pollution was a sole cause of climate change and green power.

Zang's et al. (2022) research examined the relationship between China's agricultural trade, economic expansion, and agricultural greenhouse gas concentration. The study analyzed relevant data from China from 2002 to 2020 and constructed a time-series framework for evaluation. The study predicts that China's increasing agricultural greenhouse gas emissions would eventually limit agrarian trade, which will slow down the country's overall pace of agricultural economic growth.

Furthermore, the study found that, albeit with very little effect, the expansion of the farming industry raises overall agricultural exports and lowers farming-related carbon emissions.

Adeleye et al. (2021) used yearly time series data from 1980 to 2018 to examine the effects of ecological degradation and power generated by fossil fuels on agricultural output in Nigeria. The Johansen cointegration and impulse response functions (IRFs) approaches were used in the study as part of the vector autoregressive (VAR) structure estimation method. Results indicated that whereas greenhouse gases significantly reduce agricultural output, non-renewable power enhances it. Additional research revealed that the effects of farmland, house credit, and farming communities are not comparable.

Golasa et al. (2021) investigated the sources of farming-related carbon dioxide pollution and determined the types of farmlands where reducing carbon dioxide pollution through energy efficiency was practical. Utilizing data from the Farm Accountancy Data Network (FADN), the study applied the IPCC's (Intergovernmental Panel on Climate Change) methodology to determine the magnitude of the carbon footprint. The pollution resulting from the production of power was found to be negligible when compared to other sources of pollution. Only in the horticulture crop category do emissions mostly originate from the power category. The majority of emissions come from the manufacture of cattle. Therefore, efforts to reduce pollution should n't be directed towards the renewable energy business because, aside from certain types of horticulture farms, there is n't much space for improvement.

The uneven effects of Pakistan's agricultural sector, energy consumption, and food supply on greenhouse gas emissions between 1970 and 2019 were examined by Naseem et al. (2020). An asymmetric Autoregressive Distributed Lag (ARDL) co-integration technique was employed in the study. Numerous unit root tests (ADF, PP, KPSS, Z, and A) were used as an estimation technique. The study's findings demonstrated that farming had varying short- and long-term effects on greenhouse gas emissions. The causal relationship between Pakistani agricultural output and greenhouse gas emissions was established by Rehman et al. (2019) between 1987 and 2017. The analysis results, which made use of the Autoregressive Distributed Lag (ARDL) bounds checking methods and the Augmented Dickey-Fuller and Phillips-Perron unit root tests, showed that increased seed supply and total grain production in Pakistan have a negative relationship with greenhouse gas emissions, while the persistent proof showed that cropped area, energy use, fertilizer offtake, GDP per capita, and water accessibility have a significant and positive relationship with greenhouse gas emissions.

Calzadilla et al. (2014) examined two distinct South African adaptation models and assessed the potential impacts of rising temperatures on agricultural productivity worldwide. In the study, which used an enhanced GTAP-W model that distinguished between irrigation- and humid-based farming, water was explicitly included as a component of manufacturing for agricultural irrigation. The research revealed that in order for South Africa to mitigate the adverse consequences of global environmental degradation, yield increases above benchmark expenditures in farming research and development would be necessary.

Kebede et al. (2010) examined the relationship between power use and economic growth in the Central, East, South, and West regions of Sub-Saharan Africa. Regression analysis using time series longitudinal data spanning 25 years for 20 countries revealed that the price elasticity of power demand was less than one and correlated negatively with industrialization and oil prices, but positively with GDP, population growth, and agricultural advancement. Furthermore, the results of the investigation showed that there are regional differences in the amount of power consumed. Furthermore, there are regional differences in the use of industrial renewable energy and GDP growth, and the combination of rising national demographic rates has uneven results.

There is a lack of knowledge regarding the precise effects of clean energy on economic growth and human welfare in Nigeria, despite the extensive literature on the subject. Most studies have looked at how much energy is used in general or in certain places outside of Africa. This study aims to fill that gap by looking at how the use of clean energy affects human welfare in Nigeria, taking into account particular local factors like access to electricity, standard of living, government spending on health care, and health outcomes. Policymakers in Nigeria will be able to use the information in this study to work towards more sustainable energy practices and better overall human welfare.

3. METHODOLOGY

3.1. Model Selection

To achieve the objectives of this study, the model specification is adapted from the works of Aderemi et al. (2022), Akindele-Sotunbo et al. (2022), Ajibola et al. (2021), and Osabohien et al. (2021). The model incorporates the natural logarithm for some explanatory variables and is specified as follows:

$$HWF_t = \alpha + \theta_1 LogSEC_t + \beta_2 LogGEX_t + \Omega_3 PGR_t + \mu_t \quad (1)$$

Table 1: Descriptive statistics of variables

Descriptive Statistics	EC (%)	GEX (%)	HW (Years)	PG (%)	SL (US$)
Mean	51.22347	4.147003	50.67710	2.605939	2221.079
Median	52.20000	3.880856	50.89600	2.610843	2396.036
Maximum	59.30000	7.322353	54.68700	2.680930	2688.267
Minimum	42.93612	2.366823	46.26700	2.503856	1450.784
Std. Dev.	4.649855	1.341264	2.824108	0.059767	389.4949
Skewness	−0.239926	0.891044	−0.128700	−0.300937	−0.633523
Kurtosis	1.982587	3.078765	1.665142	1.713901	2.138170
Jarque-Bera	1.107214	2.784287	1.617089	1.764265	2.054639
Probability	0.574873	0.248542	0.445506	0.413899	0.357965
Observations	21	21	21	21	21

Source: Authors' computation (2024)

The variables in the model are defined as follows: HWF (Human Welfare, measured by life expectancy), SEC (Energy Sustainability, measured by electricity production from hydroelectric sources), GEX (Government expenditure on health in billion naira), and PGR (Population growth rate).

Adapting the model in equation (1) to suit this study, we introduce a new variable (Standard of Living). Therefore, our adjusted model for this study is as follows:

$$HW_t = \alpha_0 + \alpha_1 SEC_t + \alpha_2 SL_t + \alpha_3 GEX_t + \alpha_4 PG_t + \mu_t \quad (1)$$

Where: SL = Standard of living measured by GDP per capita (constant 2015 US$).

The a-prori expectation of the study is as follows; α_1, α_2, α_3 and $\alpha_4 > 0$.

3.2. Data Collection and Estimation

This study uses annual data from 2000 to 2020, sourced from the World Development Indicators (WDI) published by the World Bank in 2023. The variables include human welfare (HW), measured by life expectancy at birth (years); clean energy consumption (EC), measured by access to electricity (% of population); standard of living (SL), measured by GDP per capita (constant 2015 US$); government expenditure (GEX), measured by domestic general government health expenditure (% of general government expenditure); and population growth (PG), measured by annual population growth (%).

To achieve the study's objectives-assessing energy consumption levels and their impact on human welfare in Nigeria-the data characteristics were first evaluated. The presence of unit roots was tested using the Augmented Dickey-Fuller test. The model was then estimated using Fully Modified Ordinary Least Square (FMOLS) regression analysis.

4. RESULTS AND DISCUSSION

Table 1 captures descriptive statistics of HW, EC, SL, GEX, PG data within the period of 2000-2020. The mean value of EC is 51.2%, this means that 51.2% of the Nigerian population consumed clean energy in the past two decades. Meanwhile, GEX has a mean value of 4.4%. This is an indication that 4.4% of the Nigerian national budget has been expended on health in the last 20 years. In the same vein, HW possesses an average value of 50.7 years. As such, the life expectancy in Nigeria is < 51 years. PG has a mean value of 2.6%. On an average basis, the rate of population growth in Nigeria is 2.6% in the past two decades. Also, SL possesses a mean value of $2,221. This implies on an average basis, annually, the monetary value of standard of living in Nigeria is $2,221.

Table 2: Unit root test

	Augmented Dickey-Fuller unit root test		
Variable	I (0)	I (1)	Decision
EC	−0.893430 (0.7629)	−4.902155* (0.0015)	I (1)
GEX	−2.301422 (0.1810)	−4.359538* (0.0033)	I (1)
HW	−1.571538 (0.4780)	0.556061 (0.9841)	I (2)
PG	−4.347055* (0.0040)	NA	I (0)
SL	−2.081036* (0.0394)	NA	I (0)

Source: Authors' computation (2024)

Table 3: Results of dynamic ordinary least squares of clean energy consumption and human welfare in Nigeria

Explanatory variable	Dependent variable (HW)	P-value
EC	-0.035291	(0.4169)
GEX	-0.010953*	(0.0363)
PG	-0.575581*	(0.0491)
SL	0.342010*	(0.0468)
R-squared	0.999972	
Adjusted R-squared	0.999531	

Hint: (*) indicates significance at a 5% probability level. Source: Authors' computation (2024)

To insulate time series analysis from the incident of spurious results, it is instructive to subject such time series to a unit root test. To achieve this, the augmented dickey-fuller unit root test was estimated in Table 2 with these results; EC and GEX possess a unit root because these variables are stationary after first differencing. Meanwhile, HW possess a higher level of stationarity due to the fact that this variable is stationary after second differencing. However, the remaining variables PG and SL are stationary at level. This indicates that the variables are free from unit roots problem. Therefore, it could be asserted that the variables in this study are mixture of I (0), I (1) and I (2).

Table 3 presents the regression estimates of clean energy consumption and human welfare in Nigeria. The following variables, EC, GEX and PG did not follow the a-prori expectation. The percent of variation in human welfare explained by the model's regressors is 99%, whereas 1% was explained outside the model. Firstly, clean energy consumption and human welfare have an insignificant negative relationship in Nigeria. A unit change in clean energy consumption causes a reduction in human welfare by 3.5% in the country. Health expenditure and human welfare have a significant negative relationship. A unit change in health expenditure reduces human welfare by 1% in Nigeria. Population growth and human welfare have a significant inverse relationship in Nigeria. However, standard of living contributed a positive and significant contribution to human welfare in Nigeria. A unit change in standard of living exerts a positive rise in human welfare by 34% in the country.

Consequently, from the findings, it could be stated that clean energy consumption did not contribute to improvement in human welfare in Nigeria. The reason for this finding could be attributed to the lack of adequate and sufficient supply of clean energy in the country.

5. CONCLUSION AND RECOMMENDATION

While estimating the relationship between clean energy consumption and human welfare in Nigeria from the period of 2000 to 2020, this study employed dynamic ordinary least squares to explore the relationship between the dependent and independent variables, with the following conclusions emanated from the study. Clean energy consumption and human welfare have an insignificant negative relationship in Nigeria. Health expenditure and human welfare have a significant negative relationship. Population growth and human welfare have a significant inverse relationship in Nigeria. However, standard of living contributed a positive and significant contribution to human welfare in Nigeria. By and large, clean energy consumption did not contribute to improvement in human welfare in Nigeria.

In the light of the above, this study recommends that when the policymakers in Nigeria wish to achieve some substantial level of human welfare in the country, policies that will drive affordable clean energy SDG-7 in the country should be embarked upon.

REFERENCES

Adebayo, T.S. (2021), Do CO_2 emissions, energy consumption and globalization promote economic growth? Empirical evidence from Japan. Environmental Science and Pollution Research International, 28(26), 34714-34729.

Adeleye, B.N., Daramola, P., Onabote, A., Osabohien, R. (2021), Agro-productivity amidst environmental degradation and energy usage in Nigeria. Scientific Reports, 11, 18940.

Aderemi, T.A., Oyegoke, A.A., Wahid, D.O., Olaoye, O.P, Ayodeji, G.B., Azuh, D.E. (2021), Human capital development, energy consumption and crude oil exports in Nigeria: Implications for sustainable development. International Journal of Energy Economics and Policy, 11(4), 443-449.

Aderemi, T.A., Alejo. A., Omoyele, O.S., Olaoye, O.P., Olanipekun, W.D., Azuh, D.E. (2022), An econometric analysis of clean energy supply and industrial development in Nigeria: Implications for sustainable development. International Journal of Energy Economics and Policy, 12(3), 209-215.

Ajibola, A.A., Sodeinde, G.M., Aderemi, T.A., Yusuf, M.O. (2021), Impact of electricity supply on the performance of small and medium-scale enterprises (SMEs) in Nigeria: A case study. Economic Insight-Trends and Challenges, 10(4), 11-24.

Akindele-Sotunbo, D., Okoh, J.I., Olanipekun, W.D., Aderemi, T.A. (2022), Energy sustainability and human welfare in Nigeria: Implications for sustainable development. Economic Insights-Trends and Challenges, XI(LXXIV), 1-9.

Akinlo, A.E. (2008), Energy consumption and economic growth: Evidence from 11 African countries. Energy Economics, 30, 2391-2400.

Akter, S., Pratap, C. (2022), Impact of clean cooking fuel adoption on women's welfare in India: The mediating role of women's autonomy. Sustainability Science, 17, 243-257.

Alaali, F., Roberts, J., Taylor, K. (2015), The Effect of Energy Consumption and Human Capital on Economic Growth: An Exploration of Oil Exporting and Developed Countries. SERPS (Sheffield Economics Research Papers Series), 015.

Asiegbu, A., Almaktoof, A.M., Khalat, A.M. (2023), Energy Access Assessment Report Focusing on Energy Poverty and Energy Demand for Rwanda. In: 2023 IEEE 3rd International Maghreb Meeting of the Conference on Sciences and Techniques of Automatic Control and Computer Engineering (MI-STA). p820-824.

Aydin, B., Demiröz, M.D. (2023), Theoretical and empirical literature of the relationship between human capital and economic growth. Finans Ekonomi ve Sosyal Araştırmalar Dergisi, 8(2), 431-448.

Ayres, R.U., Turton, H., Casten, T. (2007), Energy efficiency, sustainability and economic growth. Energy, 32, 634-648.

Bello, M. (2011), Impact of Wealth Distribution on Energy Consumption in Nigeria: A Case Study of Selected Households' in Gombe State Available from: https://www.usaee.org/usaee2011/submissions;onlineproceedings/1981RS.%20MARYAM%20BELLO.%20o%20pdf

Boggio-Marzet, A., Monzón, A., Rodríguez-Alloza, A.M., Wang, Y. (2021), Combined influence of traffic conditions, driving behavior, and type of road on fuel consumption. Real driving data from Madrid Area. International Journal of Sustainable Transportation, 16, 301-313.

Bwire, V. (2019), Solar energy: Changing rural lives in Kenya. The UNESCO Courier, 2019(3), 22-23.

Calzadilla, A., Zhu, T., Rehdanz, K., Tol, R.S.J., Ringler, C. (2014), Climate change and agriculture: Impacts and adaptation options in South Africa. Water Resources and Economics, 5, 24-48.

Chidiebere-Mark, N.M., Onyeneke, R.U., Uhuegbulem, I.J., Ankrah, D.A., Onyeneke, L.U., Anukam, B.N., Chijioke-Okere, M.O. (2022), Agricultural production, renewable energy consumption, foreign direct investment, and carbon emissions: New evidence from Africa. Atmosphere, 13, 1981.

Chontanawat, J., Hunt, L.C., Pierse, R. (2008), Does energy consumption cause economic growth? Evidence from a systematic study of over 100 countries. Journal of Policy Modeling, 30(2), 209-220.

Chopra, R., Magazzino, C., Shah, M.I., Sharma, G.D., Rao, A., Shahzad, U. (2022), The role of renewable energy and natural resources for sustainable agriculture in ASEAN countries: Do carbon emissions and deforestation affect agriculture productivity? Resources Policy, 76, 102578.

Czyzewski, A., Michałowska, M. (2022), The impact of agriculture on greenhouse gas emissions in the Visegrad group countries after the World economic crisis of 2008: Comparative study of the researched Countries. Energies, 15, 2268.

De Neve, J.E., Sachs, J.D. (2020), The SDGs and human well-being: A global analysis of synergies, trade-offs, and regional differences. Scientific Reports, 10, 15113.

Dimnwobi, S.K, Madichie, C.V., Ekesiobi, C., Asongu, S.A. (2022), Financial Development and Renewable Energy Consumption in

Nigeria, AGDI Working Paper, No. WP/22/024, African Governance and Development Institute (AGDI), Yaoundé.

Dimnwobi, S.K., Okere, K.I., Onuoha, F.C., Ekesiobi, C. (2023), Energy poverty, environmental degradation and agricultural productivity in Sub-Saharan Africa. International Journal of Sustainable Development and World Ecology, 30(4), 428-444.

Druica, E., Goschin, Z., Ianole-Calin, R. (2019), Energy poverty and life satisfaction: Structural mechanisms and their implications. Energies, 12, 20.

Falak, S.H.E. R., Abbas, A., Awan, R.U. (2014), An investigation of multidimensional energy poverty in Pakistan: A province level analysis. International Journal of Energy Economics and Policy, 4(1), 65-75.

Farthing, A., Rosenlieb, E., Steward, D., Reber, T., Njobvu, C., Moyo, C. (2023), Quantifying agricultural productive use of energy load in Sub-Saharan Africa and its impact on microgrid configurations and costs. Applied Energy, 343, 121131.

Gershon, O., Emekalam, P. (2021), Determinants of renewable energy consumption in Nigeria: A Toda Yamamoto approach IOP Conference Series: Earth and Environmental Science, 665, 012005.

Golasa, P., Wysokinski, M., Bienkowska-Gołasa, W., Gradziuk, P., Golonko, M., Gradziuk, B., Siedlecka, A., Gromada, A. (2021), Sources of greenhouse gas emissions in agriculture, with particular emphasis on emissions from energy used. Energies, 14, 3784.

Haberl, H. (2006), The global socioeconomic energetic metabolism as a sustainability problem. Energy, 31, 87-99.

Hulten, C.R., Bennathan, E., Srinivasan, S. (2006), Infrastructure, externalities, and economic development: A study of the Indian manufacturing industry. World Bank Economic Review, 20, 291-308.

Hussain, S., Yu, C. (2021), Causal relationship of energy consumption and economic growth - a case study of Pakistan. International Journal of Legal Studies, 13, 139-162.

Ikpeze, O.V., Osaro, E., Ikpeze, N.G. (2015), Analysis of energy sources, impact on environment and sustainable development referencing landmark cases in the USA, South Africa and Nigeria. Journal of Environment and Earth Science, 5, 146-154.

Imran, M., Ozcatalbas, O. (2020), Determinants of household cooking fuels and their impact on women's health in rural Pakistan. Environmental Science and Pollution Research, 27, 23849-23861.

Istekli, M., Serdengeçti, A. (2021), Beşerî sermaye ve tasarruf ilişkisi. Journal of Economic Policy Researches, 8(2), 311-326.

Juliette, M., Willy, N.F. (2021), Do energy poverty and energy consumption drive CO_2 emissions? Evidence from Sub-Saharan Africa. South Asian Journal of Social Studies and Economics, 11(4), 23-37.

Kadafa, A.A., Medugu, N.I., Stephen, D.K., Medan, J.D. (2017), The health impact of fuel wood utilization on users in Yelwa Village, Nasarawa State, Nigeria. International Journal of Sciences: Basic and Applied Research, 32, 174-191.

Karekezi, S., McDade, S., Boardman, B., Kimani, J. (2012), Global Energy Assessment: Toward a Sustainable Future. Cambridge: Cambridge University Press. p151-190.

Kebede, E., Kagochi, J., Jolly, C.M. (2010), Energy consumption and economic development in Sub-Sahara Africa. Energy Economics, 32(3), 532-537.

Li, F., Chandio, A.A., Duan, Y., Zang, D. (2022b), How does clean energy consumption affect women's health: New insights from China. International Journal of Environmental Research and Public Health, 19(13), 7943.

Li, F., Liang, W., Chandio, A.A., Zang, D., Duan, Y. (2022a), Household clean energy consumption and health: Theoretical and empirical analysis. Frontiers in Public Health, 10, 945846.

Li, H., Huang, L. (2009), Health, education, and economic growth in China: Empirical findings and implications. China Economic Review, 20, 374-387.

Lior, N. (2008), Energy resources and use: The present situation and possible paths to the future. Energy, 33, 842-857.

Liu, J., Hou, B., Ma, X.W., Liao, H. (2018), Solid fuel use for cooking and its health effects on the elderly in rural China. Environmental Science and Pollution Research, 25, 3669-3680.

Martínez, D.M., Ebenhack, B.W. (2008), Understanding the role of energy consumption in human development through the use of saturation phenomena. Energy Policy, 36, 1430-1435.

Naseem, S., Guangji, T., Kashif, U. (2020), Exploring the impact of energy consumption, food security on CO_2 emissions: A piece of new evidence from Pakistan. The International Energy Journal, 20, 115-128.

NBS. (2022), 2022 Multidimensional Poverty Index Survey. National Bureau of Statistics. Available from: https://nigerianstat.gov.ng/news/78

Nugroho, A.D., Prasada, I.Y., Lakner, Z. (2023), Comparing the effect of climate change on agricultural competitiveness in developing and developed countries. Journal of Cleaner Production, 406, 137139.

Ogwumike, F.O., Ozughalu, U.M. (2015), Analysis of energy poverty and its implications for sustainable development in Nigeria. Environment and Development Economics, 21, 273-290.

Okunola, O.S., Olagunju, I.F. (2019), Energy use and agribusiness activities of peri-urban and rural farming households in selected states of South-Western Nigeria. International Journal of Postharvest Technology and Innovation, 6, 2321-2705.

Omonona, B.T., Ajiboye, A.J. (2011), Linking poverty incidence to water resources use: Policy implications and remedies using Nigeria as case study. Journal of Economics and Sustainable Development, 2, 154-162.

Osabohien, R., Aderemi, T.A., Akindele, D.B., Jolayemi, L.B. (2021), Carbon emissions and life expectancy in Nigeria. International Journal of Energy Economics and Policy, 11(1), 497-501.

Pasternak, A.D. (2000), Global Energy Futures and Human Development: A Framework for Analysis. Oak Ridge, TE: US Department of Energy.

Pirlogea, C. (2012), The human development relies on energy. Panel data evidence. Procedia Economics and Finance, 3, 496-501.

Rehman, A., Ozturk, I., Zhang, D. (2019), The causal connection between CO_2 emissions and agricultural productivity in Pakistan: Empirical evidence from an autoregressive distributed lag bounds testing approach. Applied Sciences, 9, 1692.

Sari, R., Soytas, U. (2007), The growth of income and energy consumption in six developing countries. Energy Policy, 35, 889-898.

Sasana, H., Aminata, J. (2019), Energy subsidy, energy consumption, economic growth, and carbon dioxide emission: Indonesian case studies. International Journal of Energy Economics and Policy, 9, 117-122.

Shahbaz, M., Song, M., Ahmad, S., Vo, X.V. (2021), Does Economic Growth Stimulate Energy Consumption? The Role of Human Capital and RD Expenditures in China. MPRA Paper No. 110352.

Sher, F., Abbas, A., Awan, R.U. (2014), An investigation of multidimensional energy poverty in Pakistan: A province level analysis. International Journal of Energy Economics and Policy, 4(1), 65-75.

Sibanda, M., Ndlela, H. (2020), The link between carbon emissions, agricultural output and industrial output: Evidence from South Africa. Journal of Business Economics and Management, 21(2), 301-316.

Swarooprani, K. (2023), Component of solar energy in growth of rural India. International Journal of Science and Research Archive, 8(1), 570-572.

Tagwi, A. (2022), The impacts of climate change, carbon dioxide emissions (CO_2) and renewable energy consumption on agricultural economic growth in South Africa: ARDL approach. Sustainability, 14(24), 16468.

Tagwi, A. (2023), Agricultural economic growth, renewable energy supply and CO_2 emissions nexus. Economies, 11, 85.

The World Bank. (2021), Nigeria to Improve Electricity Access and Services to Citizens. World Bank. Available from: https://www.worldbank.org/en/news/press-release/2021/02/05/nigeria-to-improve-electricity-access-and-services-to-citizens

Todaro, M.P., Smith, S.C. (2011), Economic Development. 11th ed. Harlow: Addison-Wesley.

Tonn, B., Hawkins, B., Rose, E., Marincic, M. (2021), Income, housing and health: Poverty in the United States through the prism of residential energy efficiency programs. Energy Research and Social Science, 73, e101945.

Tran, K., Moody, G., Wu, F., Lu, X., Choi, J., Kim, K., & Li, X. (2019), Evidence for moiré excitons in van der Waals hetero structures. Nature, 567(7746), 71-75.

Twumasi, M.A., Jiang, Y., Addai, B., Asante, D., Liu, D., Ding, Z. (2021), Determinants of household choice of cooking energy and the effect of clean cooking energy consumption on household members' health status: The case of rural Ghana. Sustainable Product Consumption, 28, 484-495.

Umoh, E.A., Bande, Y.M. (2021), A template for promoting energy conservation in Nigeria's residential sector. International Journal of Sustainable Energy Planning and Management, 32, 125-138.

UN. (1987), Our Common Future. Report of the World Commission on Environment and Development, New York: United Nations. Available from: https://www.undocuments.net/our-common-future.pdf

United Nations. (2015), Addis Ababa Action Agenda of the Third International Conference on Financing for Development (Addis Ababa action agenda). New York, NY: UN General Assembly.

UNCTAD. (2017), Rapport 2017 Sur Les Pays Les Moins Avancés: L'accès à L'énergie Comme Vecteur De Transformation. Numéro F.17.II.D.6. CNUCED. Available from: https://unctad.org/system/files/official-document/ldcr2017_fr.pdf

UNDP (United Nations Development Programme). (2015), Universal Access T Modern Energy for the Pool. Available from: https://www.undp.org/content/dam/aplaws/publication/en/publications/environment-ener

Wang, Z., Bui, Q., Zhang, B., Nawarathna, C.L.K., Mombeui, C. (2020), The nexus between renewable energy consumption and human development in BRICS countries: The moderating role of public debt. Renewable Energy, 165, 381-390.

Wang, Z., Danish, Zhang, B., Wang, B. (2018), Renewable energy consumption, economic growth and human development index in Pakistan: Evidence form simultaneous equation model. Journal of Cleaner Production, 184, 1081-1090.

WHO. (2022), Ambient (outdoor) Air Quality and Health. Available from: https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health

Wolde-Rufael, Y. (2006), Electricity consumption and economic growth: A time series experience for 17 African countries. Energy Policy, 34, 1106-1114.

Wolde-Rufael, Y. (2009), Energy consumption and economic growth: The African Experience revisited. Energy Economics, 31, 217-224.

World Happiness Report. (2020), Sustainable Development and Human Well-Being. Available from: https://worldhappiness.report/ed/2020/sustainable-development-and-human-well-being

Zang, D., Hu, Z., Yang, Y., He, S. (2022), Research on the relationship between agricultural carbon emission intensity, agricultural economic development and agricultural trade in China. Sustainability, 14, 11694.

Zhao, H., Guo, S., Zhao, H. (2018), Impacts of GDP, fossil fuel energy consumption, energy consumption intensity, and economic structure on SO_2 emissions: A multi-variate panel data model analysis on selected Chinese provinces. Sustainability, 10, 1-20.

Zou, S., Zhang, T. (2020), CO_2 emissions, energy consumption, and economic growth nexus: Evidence from 30 provinces in China. Mathematical Problems in Engineering, 2020, 1-10.