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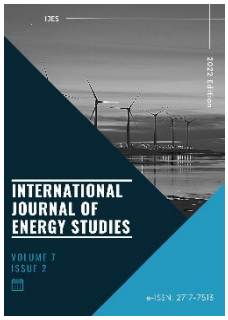

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The challenges and serviceability of solar power: suggestion on solving the Nigeria energy crisis

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Highlights

- The Nigerian Energy crisis or electricity supply crisis is continuing due to low installed capacity .
- The serviceability of solar energy to the country is crucial.
- The major challenge is the lack of public awareness

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ABSTRACT

For long decades, Nigeria has the highest population in Africa and has been struggling by slow economic growth, poor GDP per capita, high unemployment, and a host of other problems.These problems affect the country's energy sector which in turn leads to a negative crisis feedback loop. The Nigeria energy sector has been labeled by both its citizens and foreigners as a total failure in terms of economic perspective. Despite the continuous government investment over the years, there has been a slight growth in the sector with an ever-rising demand due to its population explosion, leading to a total breakdown across Nigeria economic and industrial development. This study aims to examine how the country can maximize its full energy potential by turning towards the vast quantities of solar resources at its disposal. A review of the nation's solar energy policies was done with the aim to identify the barriers hindering the country's solar development, the serviceability of solar energy to the country. Researchers attempt to demonstrate Nigeria's energy gains through the incorporation of solar energy into the country's energy resources.

Keywords: Energy crisis, solar power, challenges

1. INTRODUCTION

As the world focuses on more sustainable sources of power, the need for sustainable and renewable sources of energy has been increased. There is an ever-increasing demand for renewable sources of energy, ranging from solar energy to geothermal energy, known as renewable sources of energy available. Solar energy is known as one of the most popular sources of clean renewable energy with tremendous potential ("International Energy Outlook 2010" 2011). From the literature, researchers have proven that the sun provides the largest of all carbon-neutral energy sources. People can obtain more energy from the sun reaching the Earth in one hour (4.3 × 1020 J) than all the energy consumed on the planet in a year (4.1 × 1020 J) [1].

Nigeria is the most populous country in Africa, seventh most populous country in the world with the largest GDP in Africa (World Bank, n.d.). However, Nigeria has an ever-increasing problem of inadequate power supply especially in the rural areas as in all other sub-Saharan regions of west Africa. Nigeria is located at the equator and has over 2600 hours of sunlight per year with a solar power potential of 427,000MW or 15000PJ (about 258 million barrels of oil equivalent) [2]. However, despite the country's high solar power potential, the country's present level of total power generation, approximately 7000MW, is barely able to meet the country's population demand of about 200 million people (200,000,000). According to recent estimates, Nigeria needs about 200,000MW of electricity to be able to satisfy its ever-growing population [3]. Without taking this need into consideration, over 50% of the population will face with the lack of electricity, over 65% of the urban population will have electricity black outs for more than 12 hours per day, and just over 38% of the rural population have access to electricity [4].

The rest of the paper is organized as follows: Section 2 gives the revision and history of Nigeria solar energy, challenges of solar power in solving the Nigeria crisis are given in section 3, the serviceability of solar power in solving the Nigeria energy crisis has been discussed in section 4, and the last section concludes on the presented study.

2. NIGERIA SOLAR ENERGY REVIEW AND HISTORY

The developing nation Nigeria has to find out new possibilities to fulfill the electricity requirement and what is a better way than utilizing the resource the entire Africa is known for i.e., sun. the solar radiation level of Africa is far more than that of the other continents. (2022,Solar Energy in Nigeria

- Status, Utility and Procurement, Kamal Kashyap, Muhammad Abdullah Sani, Sushil Kumar, Naresh Kumar, Nitin Kumar and Robin Thakur).

Energy access is always a crucial factor for economic development, socio-economic activities, agricultural activities, and living standards [5]. Hence, it is very important to have stable and reliable energy access for developing countries in order to improve their economy. The sun has always been a main source of energy for energy related-activities. Therefore, it's no surprise that mankind has made several leaps in technological advances, which have also upscaled the energy that can be accessed from the sun [6]. As early as the 5^{th} century B.C, people were discovered to have built their homes in such a way that they were able to get more sunlight for heat during the winter. During the 19th century, due to ripple effects of the recent industrial revolution, inventors from Europe and America developed spectacular solar technologies that would become the today's basis of modern design [7].

Sub-Saharan Africa must be taken consideration as the one who has lack of acess of electricity about 548 million people in 2018 [8]. In Africa the development of solar energy can be traced to when east African countries, i.e. Kenya, began to support the usage of solar energy in powering the vital government infrastructure, such as the country radio and media houses in the rural areas [9]. This support led to the initial implementation of solar energy in east Africa [10].

In Nigeria, the first solar irradiation map was published by [11]. It contains 30 years of data to show the hourly and daily global solar irradiation across the country with a focus of determining the country's solar potential. The data being used, consisted of locally measured and extrapolated data. The results showed that Nigeria has an average solar irradiation of $5.2kWh/m^2$ with a majority of northern regions. [12] did research to compare Nigeria's electricity demand and production. The author concluded that demand will continue to exceed production, due to the bottleneck of transmission and distribution. Therefore, the government should consider renewables, especially solar power as an alternative to solve the energy crisis rocking the country. Analysis done by [4] showed that there was a need to understand the roots of the crisis facing the Nigeria solar industry with a focus on government policy and installation. Also, African leaders using Nigeria as a case study, and came to the conclusion that the major hindrances of solar power development are the corruption with political instability [13].

2.1. Nigeria Energy Crisis

The Nigerian Energy crisis or electricity supply crisis is generally used to describe the ongoing failure of the Nigeria power sector to supply adequate electricity which is needed to power domestic households and industrial producers. The electricity sector of Nigeria has been run for years with the use of a grid model system by the Nigerian Electric Power Authority (according to a government decree in 1973). The power authority is authorized by law to allocate power to rural and the urban dwellers in Nigeria [14]. The Nigerian national grid is known to have a total of eight generating stations for the generation of power, 28 transmitting stations which are used for major power transmission and 45 distribution districts which distribute the power generated to its populace of over 200 million people [15]. The total installed capacity as at 2018 was 11,000MW. It is worth mentioning that the effective installed capacity is just a mere 8012 MW, this is because most of these plants are over 30 years old and their maintenance schedule plagued the Nigeria energy situation [16]. The average Megawatt (MW) capacity according to the Nigerian Electric Power Authority (NEPA) is about 7555.40 MW, while the average MW availability is around 6515.18 MW showing a capacity availability factor of 42%.

Reports showed that as at 2019, 44% of the population had no access to electricity with the percentage being as high as almost 70% of the population in the rural areas. While the remaining 56% which were connected to the national grid had just over 6 hours of electricity per day, in which the average hours of electricity availability for rural areas was about 3 hours per day. The national grid has been faced with a myriad of problems across its supply chain, from outdated power plants to looting and vandalization, to even illegal connections at the distribution end [4].

3. CHALLENGES OF SOLAR POWER IN SOLVING THE NIGERIA CRISIS

There is no doubt that the major hindrance to solar power is the high cost of initial procurement and installation. This is due to, cost of the high-grade silicon and lithium for the batteries along with the other costs such as safety installation, compliant with local codes, battery maintenance etc. However, in Nigeria, the continuous current cost reduction of solar energy installation has not dropped enough to be able to encourage the adoption of individual solar investment. This is majorly due to the country's high poverty rate and high-income inequality rate. According to the report by the National Bureau of Statistics (NBS), over 40% of the country lives below the poverty line as disclosed during the Nigerian Living Standards Survey (nigerianstat.gov.ng, n.d.). As a result, the majority of the country's population cannot afford the high installation cost that comes

with individual purchase of Solar Energy. The individual cost of purchasing a low efficient diesel generator in Nigeria is almost eight times cheaper than its solar equivalent [17]. Photovoltaic solar energy is the most steady and consistent source of electrical energy [18]. Table 1 shows the cost comparison of installing solar photovoltaic (PV) systems in Nigeria with other countries [19].

Table 1. Cost of installation comparison with other countries

COUNTRY	Nigeria	South Africa	China	United States
Cost of Installing a 5 kW System	5980$	6580$	6750$	11,500$
Cost of Installing a 10 kW System	10,112$	12,074$	13,500$	18,500$
Cost in dollars/watt	1.196$	1.43$	1.35$	2.3$

Source: solarconnect.co.za; netsolar.com

The solar energy policy as published by the ECN (Energy Commission of Nigeria) [20] shows clear policy statements, road maps, target dates of implementation and documented intentions. They are clear evidence of the government's intention for sustainable energy development. Table 2 shows the general awareness and policy implementation of government grants and aids towards renewable energy in Nigeria.

Table 2. Status of government policy implementation

Policy Name	**Level of Awareness & Implementation (1-5) 1 being Low and 5 being High**
Tax reliefs for RE projects	1
Net metering framework.	2
Tax Credit for (small scale) Power Production	1
Feed-in tariffs	3
Provision of capital grants for RE startups	1

Source: Status of solar energy integration and policy in Nigeria [4]

3.1. Lack of Economic Incentives

The major problems with the solar energy policies implemented so far by the government is the lack of attractive economic incentives for private investors and this is majorly because the energy industry had been monopolized by the government until the industry broke up in 2011. The solar

energy industry is an emerging industry and the development of the industry rests on the government's ability to put in attractive economic incentives that will attract foreign investors and encourage growth.

In Nigeria, the case is even direr as there is constant government subsidies for the purchase of conventional fuel and gas for the running of individual diesel generators, which leads to a general fall in prices when compared to the running of solar startups. However, it is counter-productive and unsustainable as the fuel subsidies are only temporary and as such will have a lasting impact of hindering the development of the solar industry. Also, the proposed Feed-in-Tariffs (FiT) which have been known to be a major booster for the adoption of solar energy has been of no significance since it still compares at relatively low profit to the country's conventional sources of energy. The proposed FiT varies from 68 NGN/MWh (US$0.1786) to 93 NGN/MWh (US$0.2447) as at 2018 for renewables in the country; this is still very low to encourage any profitable investment by intending investors, Table 3 shows a summary comparison of economic incentives for renewable energy compared with other countries.

Table 3. Comparison of Nigeria economic incentives along with other countries

COUNTRY	NIGERIA	SOUTH AFRICA	CHINA	UNITED STATES
Tax Credit	Non-Available	28% of Total Installation cost as Tax Bonus	50% of VAT for manufactures and consumers	30% of installation cost as Tax Bonus
Research and Development	YES	YES	YES	YES
Feed in Tariff (FiT) in $	0.0017 - 0.0024	0.160 – 0.260	0.075 - 0.11	0.0573 - 0.0995
Customs Duty	2 years Exemption	NO	YES	YES
Tax Holiday/ Credit for Manufactures	5 Years	YES	NO	NO
Low Interest Loans	Yes	YES	YES	YES
Grant to Communities	Yes	YES	YES	YES

Source: nrel.gov, westerncape.gov

3.2. Lack of Public Awareness and Acceptance

Public acceptance, especially about renewable energy technology, is usually associated with the people's beliefs, attitude and perceptions of such technology. Moreover, the public awareness of the serviceability of solar panels is vital for renewable energy technology's development and survival. As public awareness causes social acceptance and a positive change in consumer behavior, the survival and development of any product is based upon consumers' demand. This affects the level of marketing and awareness about a particular product. For the Nigerian solar industry, one of the major hindrances to its development is the lack of public awareness as to the serviceability of solar power in solving the energy crisis.

[21] showed that the Nigerian public knowledge and awareness about solar energy was rather outdated. It was shown that while 87% of the urban population do have some knowledge as to the existence of solar energy, many of them do not consider it to be an economic source of power at their home. Results also showed that of the 87% who have some level of literacy about solar power, only 8% were willing to purchase solar energy, and the remaining 78% commented that solar panels were too expensive and inefficient in producing the adequate amount of energy required. Despite the favorable literacy rate of 92% among the urban population of Abuja (the capital city of Nigeria), the research of [16] showed that many of them still refused the acceptance of solar energy at their homes by stating the novelty of the technology, the reliability and safety of the batteries used for power storage as are the major reasons. However, this is reasonable as the high initial capital cost of solar PV in homes causes anyone to want some assurance and guarantee on the product. As the most modern solar PV panels usually have a warranty of about 20-30 years, these concerns of urban populace can be excluded.

4. SERVICEABILITY OF SOLAR POWER IN SOLVING NIGERIA ENERGY CRISIS

With high upfront cost being the major factor as to why solar is not appealing compared to conventional energy, therefore, low cost can be listed as one of the important serviceability factors for solar power utilization. This is however promptly true due to the fact of the high cost of diesel generators, which is very common among all sectors of the Nigeria energy consumption populace. The use of expensive diesel generators by the manufacturing industries has had an explosive impact with energy cost of production in Nigeria being at 40% of total cost, and being as expensive as nine times that of China. In addition to the reduction in the cost of production due to expensive diesel generator maintenance, the production capacity of the manufacturing industry was also

affected due to the loss of production. Report showed that despite the fact that only 6.2% of manufacturing firms relied solely on the national grid, 44% of total overall firms attributed a fall of 20% - 49% of their capacity as a result of energy shortage [22].

Reports by the Manufacturers Association of Nigeria (MAN) showed that the manufacturing industry needed roughly 2000MW of electric power to run its operational plant as at 2010. But, due to the deficiency of the National electricity grid and reliance on diesel generators it spends more than 12 million dollars per week only on the maintenance of diesel generators. Figure 1 shows the electricity consumption of Nigeria based on sectors, ie. residential, commercial and industrial. As it can be seen from Figure 1, the residential sector with 45% has the higher electricity consumption than the other two sectors, i.e. industrial and commercial, with 30% and 25% respectively.

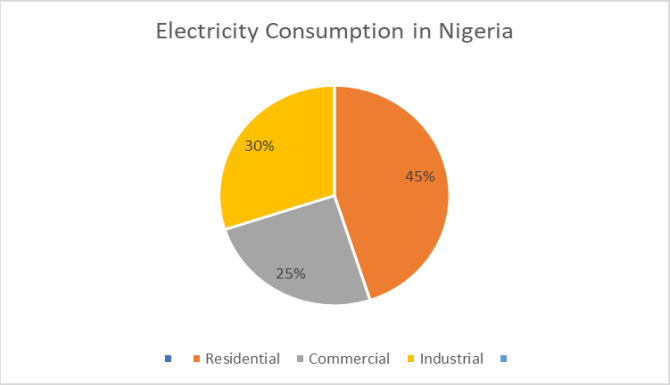

Figure 1. Electricity comsumption in Nigeria by sector

4.1. Analysis of an Average Income Home with Diesel Generator

An average high-income home in Nigeria uses a standard 4KVA generator set to offset the backdrop in electricity from the national grid. On the average, the 4KVA generator consumes 2.2 liters of fuel/hour (Assurancepower.com, n.d.). Eq 1. shows the total cost (TC) for the usage of generators in a year [23].

$$TC = n * d * L * c \quad (1)$$

where $d =$ days per year for usage of the generator ; $n =$ hours per day for usage of the generator; L = liters usage of fuel per hour; $c =$ average cost ($) of fuel in Nigeria per liter.

A sample calculation can be given as follows by assuming $d = 10$ hrs, $n = 365$ days , L = 2.2 liters, $c =$ 0.5$/liter :

TC = 10 hours × 365 days x 2.2 liters x 0.5 $/liter = 4,015 $ per year

The average high-income home with a 4KVA generator will spend about 4,000$ excluding the cost of generator purchase and technical maintenance (*The Potential of Nigeria's Residential Solar Rooftop Systems*, 2015). Note that this is not the case with low-income homes which use lower capacity generators and less hours per day for the usage of generators. The average cost of a 4KVA generator in Nigeria is 1421$. The total price of installation and running cost will be 5436$ (= 4015$ + 1421$).

Over the past decade the price of solar power technology has been falling, with the average installed cost per kilowatt being at 2.41$/watt. In Nigeria, however, the average cost of a 4KW solar PV system with battery and 20 years warranty is 8,800$. This price is lower than world's average as Nigeria mostly imports from China (*The Potential of Nigeria's Residential Solar Rooftop Systems*, 2015). Therefore, in comparison with diesel generators, the solar power is expensive at initial upfront cost, but the break-even point when compared with diesel running generators, is just less than 2 years. This value is expected to continue decreasing as the overall world price for solar technology continues dropping by the aid of new stable government policies which support the use of solar technology.

4.2. Bridging the Enrgy Gap

The population of Nigeria has risen exponentially compared to its electricity growth. This is majorly due to the fact that the rural sparsely distributed population of the region have not yet been connected with the energy grid. A graphical representation of Nigeria energy gap is given in Figure 2.

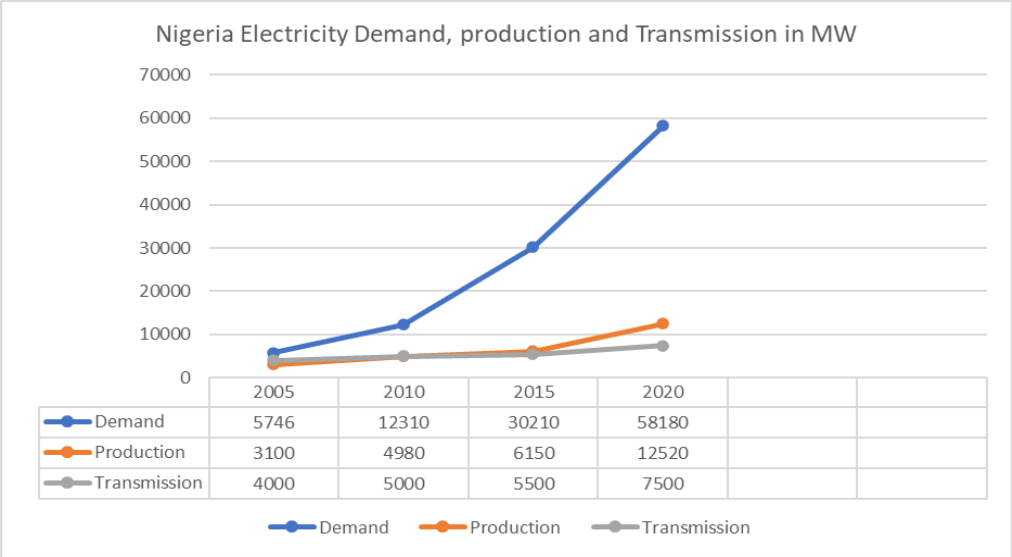

Figure 2. Nigeria electricity demand, production & transmission

The current energy demand for Nigeria, a developing nation with an exploding young population, is inadequate as 58,150 MW and this figure is expected to continue growing exponentially as the population continues to grow. And, as more people are lifted up from poverty causing increase in demand as the standard of energy improves. But these will create a sustainable market for the solar industry as the incorporation of solar into the Nigerian energy sources.This will be a major leap forward in tackling the ever-widening Nigerian energy crisis.

4.3. Acceleration of Rural Electricity and Development

As all developing countries, most of Nigeria's population are located in rural areas with little or no access to basic amenities. Due to lack of community access to the national grid, the majority of rural areas are without full access to basic amenities such as health issues. With the help of solar energy into the energy source, rural communities can be able to power up their clinics and also operate during nighttime. Also, recent studies have shown that the use of solar energy requires that every medical facility, especially in rural areas, have access to at least one renewable and sustainable energy source. Meaning that every hospital, clinic and rural health infrastructure will be mandated to have its own source of renewable energy production [24].

Therefore, one of the major serviceability of solar energy in Nigeria is to supply electricity to the rural areas. These rural areas are very widely far apart and with little electricity consumption and so many of them are yet to be connected to the grids. The solar energy mini grid points across the

country will not only create new working areas, but also help in bringing light to these rural areas, which will end up with development.

Nigerian rural communities will undoubtedly be one of the biggest beneficiaries as installing renewable energy such as solar energy is often labor intensive and requires digital skills. As many of these rural communities have a young and vibrant population, the skills of these local community youth will be in consistently high demand with the fact that solar industries will be developed. The new working areas will have a positive impact as more rural communities get access to energy, and this will further aid in development and an increase in living standards. The Nigeria population is expected to be ever growing, therefore, it can be said that the solar industry will not only serve to aid in the new working areas for rural communities, but will also create sustainable jobs [25].

4.4. General Environmental and Health Improvement

The World Health Organization (WHO) argues in its report that about 20% of total carbon emissions are accredited to energy and fuel used by the residential sector of the society (World Bank, n.d.). It's no doubt because using renewable energy will generally contribute to public health as less pollution such as CO_2 and SO_2 in the atmosphere. In Nigeria, the use of diesel fuel running generators have also become a norm among the upper and middle-class homes in its urban areas. This is due to the fact, the average electricity availability runtime from the national grid is about 5.4 hours every day, and so individuals rely on their backup generators for power during the blackouts from the national grid. With the constant use of these generators for long periods by a multitude of people in over congested cities, pose a serious crisis to public health.

The case is not any better for the rural areas. The majority of Nigeria's rural areas have no access to the national grid. Coupled with the fact that these are low-income earners living in rural areas where the only source of energy at their disposal is "wood fuel". The use of solid fuel (charcoal, peat, wood, wood pellets, crop residues) as a primary energy source is one of the reasons for the dangerous health crisis. Research has shown that the burning of wood fuels releases a number of pollutants such as particulate matter or soot, nitrogen oxide, carbon dioxide, carbon monoxide and other dangerous chemicals. Wood combustion has also been known to contribute negatively to both indoor and outdoor air pollution. Wood fuel has been known to be the leading environmental health risk factor worldwide and is responsible for 2.8 million premature deaths each year

(Ukachukwu, 2003). Apart from the direct deaths each year, the accumulation of these chemicals over time has been proven to be a major cause of diverse diseases such as lung cancer and other respiratory problems. The cost of this to public health is high, as Ukachukwu (2003)showed that diesel exhaust contains more than 40 toxic air contaminants, including many known or suspected cancer-causing substances, such as benzene, arsenic, and formaldehyde. In Nigeria where smoking is intolerant, lung cancer is indicated to be on the rise by 6%. Regional surveys also showed that the asthma prevalence among adults increased from 5.1–7.5% in 2003 to 24% -28.3% in 2016, and outdoor pollution was reported as an important risk factor by participants [26].

4.5. Energy Security

Energy security can be defined as the availability/access to natural resources for the sole aim of energy consumption. This can be divided into short term security which involves the formulation of trade partners and contract; as well as long term security which involves reducing a country's dependence on one form or an imported energy. As [26] showed that Nigeria relies majorly on thermal gas power plants, with the majority of its electricity production (totally 87.5%) coming from thermal and gas power plants while 10% coming from hydro stations. The raw material fed into thermal gas power stations come majorly from the south region. This shows that in a time of war or crisis, if only this part of the country is lost, the entire nation can be in jeopardy. The introduction of renewable energy such as solar energy will not only serve as a sustainable source of energy, but will also diversify the nations' reliance on conventional oil and gas which come from just a single region of the nation's six geopolitical zones.

5. CONCLUSION

The Nigerian energy crisis has occurred due to the country's current reliance on conventional sources of energy which create monopolies with gross inefficiencies. This led to individuals seeking other energy sources, like diesel generators in urban areas and use of wood fuel in rural areas, to satisfy the current electricity blackouts which rock the country. The location of Nigeria which is at the equator, especially the northern part of the region which is just below the Sahara Desert makes it a good place for the utilization of solar energy. This location makes for about 2800 kwh/m^2 available per year which is more than enough to meet the country's daily demand. Utilization of just 1% of the total land area of the country for solar production will generate a theoretical power of about 185,000 GWh which is about 10 times more than the country's electricity demand. Apart from government policies, the major challenge is the lack of public

awareness due to the fact that a lot of the citizens are used to the diesel generators. They are not aware that the 1-year running cost (installation and maintenance cost) of a diesel generator is equivalent to the cost of solar power with similar capacity for 25 years.

The marginal high solar installation cost which is usually the major hindrance to the development of solar energy is currently reduced with the development of new technologies. As coupled with almost no maintenance cost, it can be enough economical reason for the application of solar industry that the nation should consider especially in the rural areas.

The serviceability associated with the increased usage of solar energy in a country like Nigeria, has many benefits for improving the economy, general public health services, etc. These benefits can be listed as bridging the energy gap, energy security, new working areas, supply energy sources and development of rural areas, disposal of diesel generators and wood fuel.

DECLARATION OF ETHICAL STANDARDS

The authors of the paper submitted declare that nothing which is necessary for achieving the paper requires ethical committee and/or legal-special permissions.

CONTRIBUTION OF THE AUTHORS

Ayşe Tansu: Supervised the work done and wrote the manuscript.
Ayomide Titus Ogungbemi: Performed the experiments and wrote the manuscript.
Fatma Tansu Hocanın: Analyzed the results and wrote the manuscript.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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