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INVESTIGATION AND CHARACTERIZATION OF ELEMENTAL COMPOSITION OF SOLAR PANEL

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Abstract
This research focused on the investigation and characterization of the elemental composition of solar panels available in Nigeria, with a view to making recommendations for the indigenous production of solar panels using locally sourced materials as semiconductors. The ZEISS Ultra Plus Scanning Electron Microscope (SEM) machine was used to obtain the structural pattern of the samples. In order to carry out the elemental composition of the samples, EDX analysis was performed using the Energy Dispersive X-ray (EDX) machine, and the result was measured in atomic weight %. The result showed that the elements present in the solar panel from China were evenly distributed, the same as the elements present in the panel from Canada, while the elements present in the panel from Germany were not evenly distributed. In sample A (China), the number of elements present was Silicon (45.00%), Oxygen (34.30%), Sodium (16.20%), and Aluminum (4.50%); in sample B (Canada), Silicon (50.43%), Oxygen (39.90%), Zinc (4.80%), and Aluminum (4.87%) were present; In comparison, in sample C (Germany) with Silicon (50.42%), Oxygen (39.90%), Nickel (4.83%), and Aluminum (4.85%) were present. Silicon is the main element present as it is the semiconductor material used. It was used because of its semiconducting properties, ability to release electrons when exposed to sunlight (either monocrystalline or polycrystalline), and stability and reliability. Other elements like aluminum and silver form metal contact on the solar cell's surface, and they serve as catalysts that facilitate the flow of electrons. Thus, this study has laid the foundation for elements available in solar panels to guide indigenous researchers and business ventures interested in the elemental constituents of solar panels for business and production purposes.

Keywords: *Analysis, elements, elemental composition, solar panel.*

Introduction

The growing global population has put more demand on energy (Ukoba et al., 2018). There is increasing need for transportation of human, livestock and goods, demand for electricity for powering industrial and domestic appliances also demand for energy for heating, cooking, lightening among other needs. This has resulted in the use of fossil fuels. However, fossil fuels have been discovered to cause over 75% of global warming (Intergovernmental Panel on Climate Change, 2021). Further research and development led to renewable energy. Renewable energy are energy sources that is clean, sustainable and does not deplete as they are renewable. They include solar, wind, hydropower, tidal, biofuel, and small modular reactor among others. Solar, hydropower and wind are the most widely used renewable energy sources worldwide.

Solar power is the process of turning solar energy directly into electricity using photovoltaics or indirectly through concentrated solar power (Gad et al., 2023). The photovoltaic effect is used by photovoltaic cells to transform light into an electric current. Solar Energy is a form of renewable energy. It converts sun energy into electricity. It uses a solar panel to trap the energy from the sun to generate electricity.

Nigeria has a land mass of about 924,000 km2, population of around 170 million, and lies within latitudes 4.32°N and 14°N and longitude 2.72°E and 14.64°E (Shaaban and Petinrin, 2014). It is located where it experiences a huge solar energy resource, of about an average of 4−6.5 kWh/m2 per day, increasing from the southern to the northern part (Akinyele et al., 2015). Furthermore, the country has an electricity access deficit rate of about 60% (Rudnick, 2014), of which the rural dwellers are worst-hit by energy poverty.

For Nigeria to meet its visionary plan of increasing electricity access to an appreciable level by 2025, (e.g. Renewable Energy Master Plan) and fast-track its sustainable development goals, concerted efforts must be made, one of which is the development of solar panel plants across the six geo-political zones of the country, that could help to address the problem of dependence on importation of PV modules, create new business opportunities, and to also strengthen the rural development programmes. Figure 1 shows the solar resource map that display the solar photovoltaic power potential of Nigeria.

Solar panel technology continues to evolve, with ongoing research and development aimed at improving efficiency, reducing costs, and minimizing environmental impact. Solar panels, also known as photovoltaic (PV) panels, are designed to harness sunlight and convert it into electricity.

The elemental composition of solar panels primarily revolves around semiconductor, conductor and connectors, encapsulation material, front and back cover, and mounting frame.

Three types of solar panel exist viz monocrystalline, polycrystalline, and thin films (Ogunjuyigbe et al., 2021; Ghazali and Rahman, 2012) as shown in Table 1.

Understanding the elemental composition of solar panels is essential not only for their efficient functioning but also for assessing their environmental impact and recyclability. The specific composition and materials used may vary depending on the type of solar panel, manufacturer, and technology (e.g., monocrystalline, polycrystalline, thin-film),

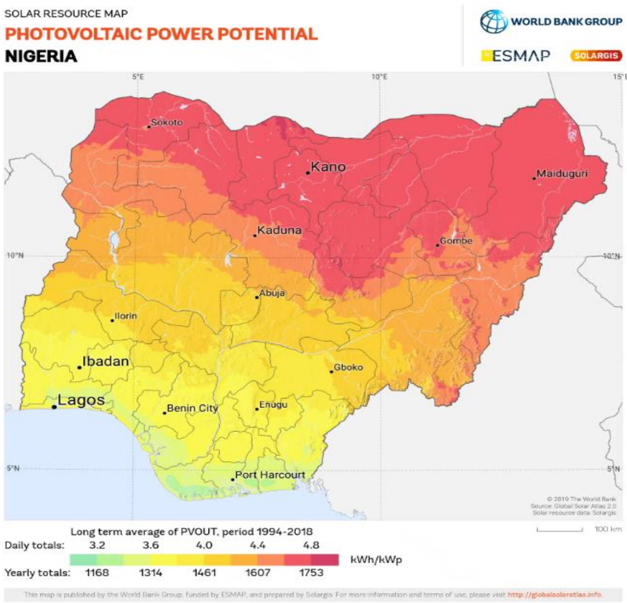


Figure 1: Nigeria solar resource map (Courtesy: World Bank Group ESMAP)

Table 1: Table of different types of solar panels

Solar Cell Type	Advantages	Disadvantages
Monocrystalline (Mono-SI)	High efficiency; high life-time value	Higher cost
Polycrystalline (p-Si)	Lower cost	Lower efficiency; lower lifespan
Amorphous (A-SI)	Flexible and portable; relatively low costs	Lowest efficiency

but there are fundamental elements common to most solar panels.

Therefore, this study aims to study the elemental composition of solar panels available in Nigeria.

Materials and Method

The equipment and tools used for this research work are: Photovoltaic (PV) solar panel, ZEISS Plus Scanning Electron Microscope machine, Energy Dispersive X-ray Skyray EDX3600B machine, hammer, electric tools, heat guns, multimeter, cutters, mallet, and screwdriver.

Testing prior to Purchase

Based on the market survey, three solar panels were purchased as shown in Figure 2 to Figure 4. They are made from the following countries: Canada (monocrystalline), Germany (polycrystalline) and China (polycrystalline), rated 300W, 10W and 100W respectively. A Multimeter was used to ascertain if the information written on the nameplate of the solar panels correspond to what they deliver.

(a) (b)

Figure 2: 300 W Monocrystalline solar panel made in Canada (a) the solar module (b) name plate

(a) (b)

Figure 3: A 10 W polycrystalline solar panel made in Germany (a) the solar module (b) name plate

(a) (b)

Figure 4: A 100 W polycrystalline solar panel made in China (a) the solar module (b) name plate

Destructive Process

To ascertain the solar panel's elemental composition, the sample preparation process involved mechanically separating the panel's components. As seen in Figure 5, disassembly entails removing the aluminum frame, wires, sandwiched panel junction box, and rear polymer, semiconductor, and glass component assembly. Electric tools, heat guns, all-purpose tools (screwdrivers, hammers, mallets, and cutters), and personal protective equipment (PPE) were utilized for disassembly in a safe manner.

After disassembly, three different samples were prepared from the three different panels as follows: China sourced solar panel (Sample A), Canada sourced solar panel (Sample B) and Germany sourced solar panel (Sample C)

Elemental Composition Analysis

The elemental composition analysis of sample A, B and C was done using the Skyray EDX3600B spectrometer Energy Dispersive X-ray (EDX) machine. The machine showed the element present in the solar panel detailing their weight percentage and atomic weight percentage.

The morphology (structural pattern) of the samples were obtained using the ZEISS Ultra Plus Scanning Electron Microscope machine.

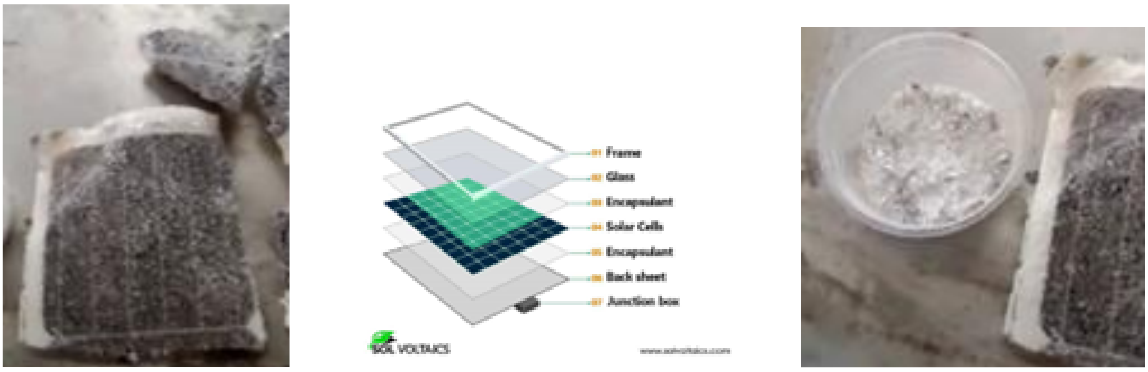
Results and Discussion

Destructive Test Result

On breaking the solar panel, it was discovered that a typical solar panel contains the several layers sandwiched together with unique materials as found in Samples A, B and C. The layers include: Frame, Glass, Encapsulant, Solar Cells, Backsheet and Junction Box as shown in Figure 6. These materials play different role in the solar panel.

(a) (b)

Figure 5: Destructive Process on the sourced solar panels (a) solar panel (b) cut-out solar cell



(a) (b) (c)

Figure 6: Different layers of solar panels (source: solvoltaics.com)

The ability of solar panels to absorb sun radiation, convert it to electricity is due to the composition of the solar panel. It was observed that the three solar panels are made up of several layers. The top layer is made up of glass. This glass is clear enough for sunlight to pass through but is strong enough to keep the layers below safe. Below the glass lies an antireflective coating and contact grid. Then, there is the electricity-producing portion. Next lies two layers of semiconductor Silicon. Arranged in several solar cells, the Silicon absorbs sunlight, or more specifically, photons. Photons, which are particles of light, push electrons from their atoms, causing them to move around through a positive and negative charge. This movement of electrons creates a flow of direct current or DC electricity.

The layers of Silicon and other elements that were identified in the elemental composition result were sandwiched between two layers of encapsulant to keep everything together. On the bottom is a backing layer to keep the inner portions safe from the elements and an aluminium frame wrap around the edges.

Elemental Composition Analysis Result

A Scanning Electron Microscope (SEM) machine was used to obtain the morphology of the sample. An Energy Dispersive X-ray (EDX) machine was used for detecting the elements present in the sample.

a) ***Sample A***: A ZEISS SEM was used to obtain the morphology of the solar panel imported from China and the micrograph is shown in the Figure 7.

It can be seen that the elements are almost evenly distributed. The elemental composition analysis of the solar panel from China is shown in the Figure 8.

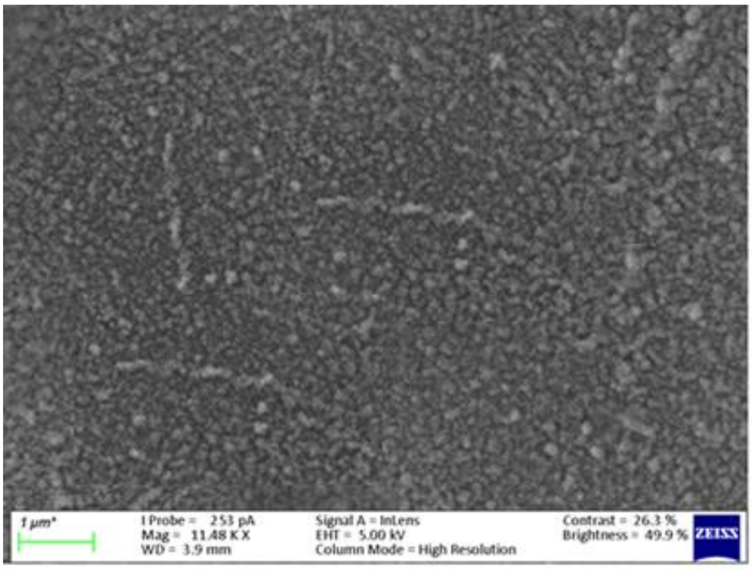


Figure 7: A SEM image of Sample A

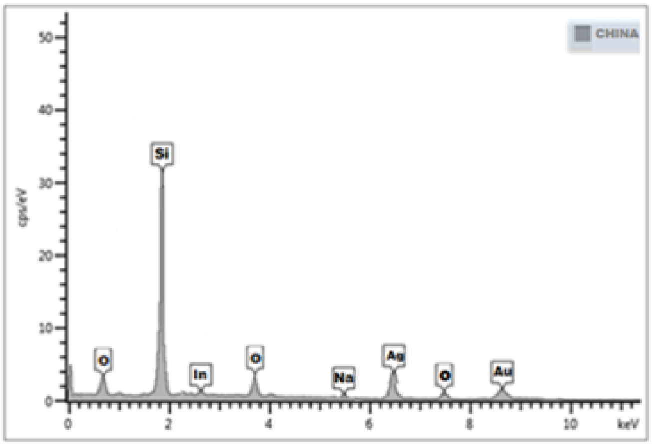


Figure 8: Elemental composition of Sample A

It can be observed from the EDX that solar panel imported from China contains the following elements measured in atomic weight %; Silicon (45.5%), Oxygen (34.30%), Sodium (16.20%), Aluminium (4.5%) and small traces of Indium oxide, Gold, Silver and Sodium Oxide. The semi-conducting material is Silicon which is what attracts and capture the photon in the sunlight. When the photons hit the solar panel, Silicon absorbs it and create an electric field resulting in flow of electron and eventual electricity. This material is what converts the incident sunlight into electricity. This is done by sunlight knocking an electron. The movement of the electron to occupy a hole is what results in electricity generation. Materials such as sodium oxide forms part of the composition of the solar panel with function including to protect the panel, diffract unwanted packet of sunlight.

b) ***Sample B:*** The SEM image of the solar panel from Canada is shown in the Figure 9. It shows a better image with surface evenly aligned and distributed.

The EDX of the panel imported from Canada is shown in the Figure 10. It was observed that there are more elements when compared to that from China.

The element presents in the solar panel imported from Canada include Silicon (50.43%), Oxygen (39.90%), Zinc (4.80%), and Aluminium (4.87%) measured in atomic weight % with Indium Oxide,

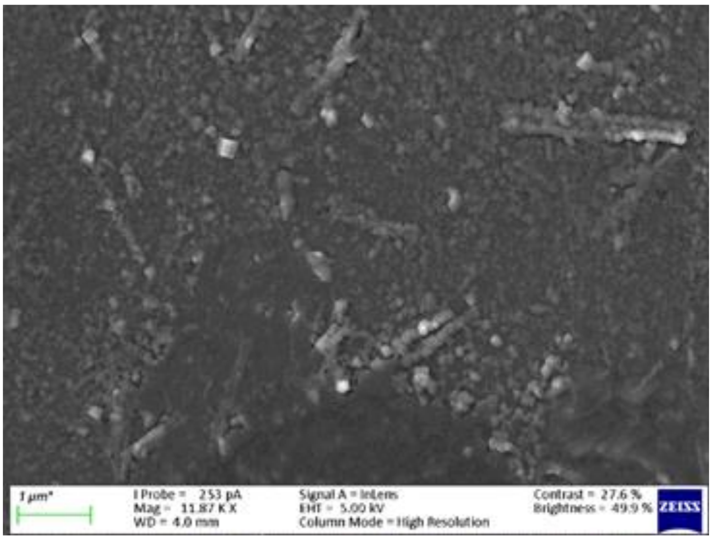


Figure 9: A SEM image of Sample B

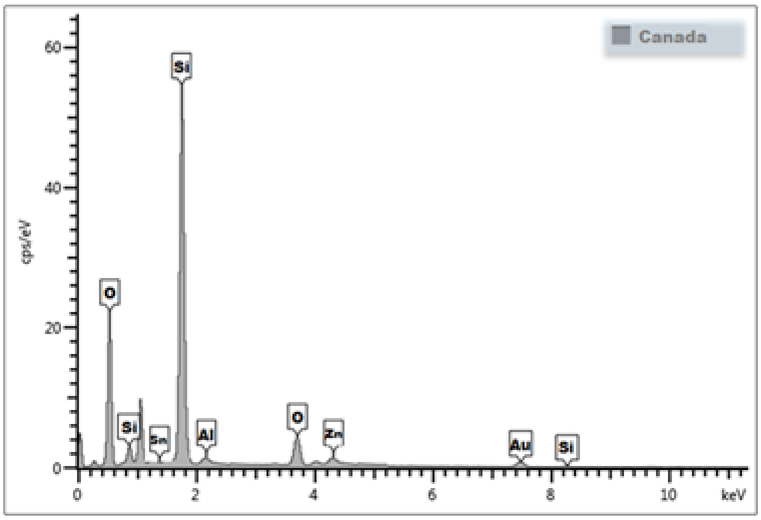


Figure 10: Elemental composition of Sample B

Aluminium, Gold, Silver and others in traces as seen in Figure 4 above. As earlier stated, the semi-conductor material is Silicon that absorbs the photon. The Indium Oxide is the conducting glass substrate. Materials such as Aluminium, Sodium Oxide forms part of the composition of the solar panel with function including to protect the panel, diffract unwanted packet of sunlight.

c) ***Sample C:*** The Figure 11 shows the SEM image of the solar panel imported from Germany.

The EDX image of the solar panel from Germany is shown in the Figure 12. The element present in the solar panel imported from Germany include Silicon (50.42%), Oxygen (39.90%), Nickel (4.83%), Aluminium (4.85%) measured in atomic weight %, with Indium Oxide, Tin, Gold, Silver and others in traces. The other includes Sodium Oxide, Lead and Magnesium. The semi-conductor material is Silicon that absorbs the photon. The Indium Oxide and Tin Oxide are the conducting glass substrate. Materials such as Nickel Oxide, Sodium Oxide forms part of the composition of the solar panel with function including to protect the panel, diffract unwanted packet of sunlight.

The elemental composition of each sample is presented and summarized in the Table 2.

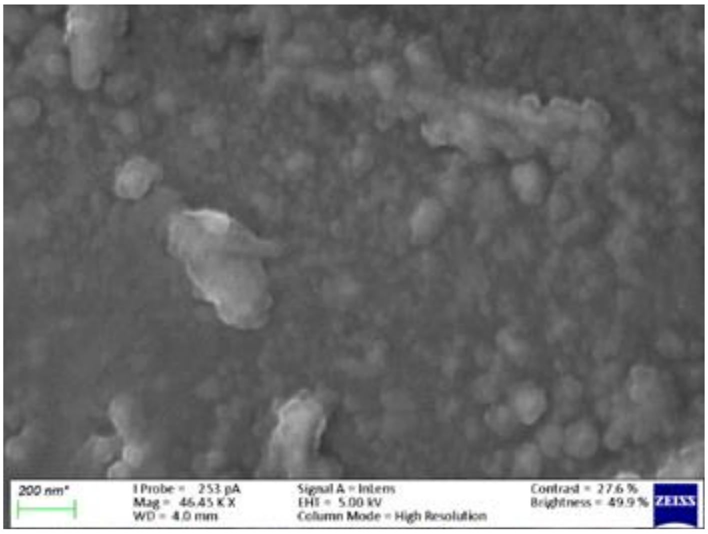


Figure 11: SEM image of Sample C

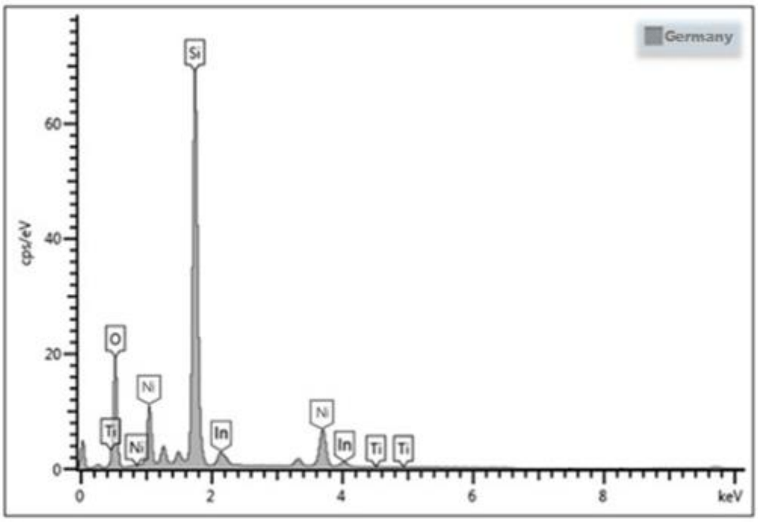


Figure 12: Elemental composition of Sample C

Table 2: The elemental composition of all three samples

Elements	Sourced PV Solar Panels			Average (wt %)
	Sample A (wt %)	Sample B (wt %)	Sample C (wt %)	
Si	45.00	50.43	50.42	48.62
O	34.30	39.90	39.90	38.03
Na	16.20	NA	NA	5.40
Al	4.50	4.87	4.85	4.74
Zn	NA	4.80	NA	1.60
Ni	NA	NA	4.83	1.61
Total	**100**	**100**	**100**	**100**

Functions of the Elements Present in the Solar Panel

Based on the elemental composition result gotten by using the Skyray EDX3600B spectrometer machine, the following was analysed as the function of each of the element present in the solar panel composition of Sample A, B and C.

1. Silicon (Si): It is the primary semiconductor material present in the solar panels and makes up the bulk of the panel's composition. Sample B (Canada) has the highest Silicon composition of 50.43%, followed by Sample C (Germany) with 50.42% and Sample A (China) having the least Silicon composition of 45.00% all measured in atomic weight %. Its unique crystalline structure allows it to act as a semiconductor (allowing the flow of electricity). It was used also because of its ability to release electrons and enables the control of the movement of released electrons when exposed to sunlight due to its atomic structure (either as monocrystalline or polycrystalline), facilitating the conversion of light energy from the sun into electrical energy - Direct Current (Ogunleye and Awogbemi, 2011).

2. Hydrogen (H), Oxygen (O) and Carbon (C): These elements are present in compound which make up the encapsulation and protection layers. They form the tempered glass which protect the semiconductor material from environmental factors and mechanical damage (Abdullahi et al, 2020). The glass primarily consists of Silicon dioxide (SiO_2). The back-sheet is a protective layer on the rear side of the solar panel. It can be made of materials like Polyvinyl Fluoride (PVF) or polyester.

3. Silver (Ag): Silver is widely used as the front metal contact material in solar cells. It is highly conductive and transparent, allowing sunlight to pass through to the active semiconductor (Silicon) layers while efficiently collecting and transporting the generated electrical current. Its low electrical resistance minimizes energy losses within the cell, ensuring that a large portion of the generated electricity can be extracted and utilized.

4. Aluminum (Al): Aluminum is commonly used as the back metal contact material. It serves as the electrical contact on the rear side of the cell, providing a pathway for the generated electricity to flow out of the cell. Aluminum also acts as a reflective layer, helping to redirect photons that have passed through the active semiconductor layers back into the cell for absorption. This enhances the efficiency of the cell by increasing the chances of photon absorption and conversion into electricity.

5. Copper (Cu): Copper is commonly employed as the material for interconnecting wires within solar cell modules or arrays. These wires connect individual solar cells in series or parallel configurations, forming a larger photovoltaic system. Copper traces are also used within the solar cell structure to create electrical pathways for current flow. These traces help distribute the electrical charge efficiently across the cell's surface, reducing resistive losses and optimizing power output. Copper busbars are often utilized to collect current from multiple cells within a module and to transport it to the output terminals. They provide a robust and low-resistance connection, ensuring reliable electrical performance and minimizing energy losses.

5. Silicon Nitride (Si_3N_4) or Titanium Dioxide (TiO_2): These are used as Anti-Reflective Coatings (ARC) on the panel. Solar panels most times have anti-reflective coatings which help improve light absorption. These coatings can contain various compounds such as Silicon Nitride (Si_3N_4) or Titanium Dioxide (TiO_2) (Zarma, 2017).

Conclusion

This research seeks to investigate and characterize the elemental composition of solar panel available in Nigeria. A destructive test performed on the three purchased solar panels from China, Canada and Germany showed that every solar panel is made up of several layers sandwiched and produced with different materials. Each of these layers have their unique role in the solar panel. An elemental analysis of the samples was carried out using the Skyray EDX3600B machine. It was discovered that certain elements were found in common in the three solar panels which are; Silicon, Aluminum, Glass and Gold. Silicon is the dominant semiconductor material in most solar panels, but various other materials are used in their construction, including metals, glass, plastics, and adhesives. The precise composition can vary between different types and brands of solar panels. Overall panel efficiency can be influenced by many factors, including; temperature, irradiance level, cell type, and interconnection of the cells.

Solar energy is an affordable and sustainable energy solution that will solve most of the energy needs of Nigeria. Researchers in Nigeria should engage actively in developing solar cells that will change the solar energy industry in Nigeria. This will lead to setting up of more companies producing solar panels.

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