Harnessing Solar Energy and Building Integration Technology in Nigerian Residential Buildings: Opportunities and Challenges

DOMINIC A. OBODOH[1], EUCHARIA C. ENEBE[2], AGATHA T. CHUKWUENYE[3]
[1]Department of Building, Nnamdi Azikiwe University Awka, Nigeria
[2, 3] Department of Building, Enugu State University of Science and Technology, Enugu Nigeria

Abstract- Nigeria's energy crisis and tropical climate make solar energy an attractive solution. This study explores the application of solar energy and building integration technology in Nigerian residential buildings, focusing on energy efficiency, cost-effectiveness, and sustainability. We examine the potential of solar thermal, photovoltaic, and optical technologies in Nigeria's residential sector, considering factors like building design, materials, and climate. Challenges and opportunities in implementing solar energy systems in Nigeria are discussed, including policy frameworks, financing, and public awareness. Our findings highlight the potential for solar energy and building integration technology to address energy access and sustainability challenges in Nigeria, providing recommendations for stakeholders to promote widespread adoption.

Indexed Terms- Solar Energy, Integration Technology, Residential buildings, Opportunities and Challenges.

I. INTRODUCTION

Nigeria, Africa's most populous nation, faces significant energy challenges, including inadequate electricity supply, high energy costs, and a heavy reliance on fossil fuels. However, the country also boasts an abundance of solar resources, making solar energy a viable solution to its energy woes. The integration of solar energy systems into residential buildings offers a promising approach to addressing energy access, sustainability, and climate change concerns. Building integration technology, which involves designing and constructing buildings that optimize solar energy absorption, can further enhance the efficiency and cost-effectiveness of solar energy systems and ensure a zero-energy building (Sambo, 2019).

A zero-energy building is a building that is designed for zero net energy emissions and emits no carbon dioxide. Building- integrated PV (BIPV) technology is coupled with solar energy sources and devices in buildings that are utilized to supply energy needs. Thus, building-integrated PVs utilizing thermal energy (BIPV/T) incorporate creative technologies such as solar-cooling. (Kylili and Fokaides, 2014).

Despite the potential benefits, the adoption of solar energy and building integration technology in Nigerian residential buildings remains limited. This research aims to explore the opportunities and challenges associated with harnessing solar energy and building integration technology in Nigerian residential buildings, identifying barriers, opportunities, and recommendations for stakeholders to promote sustainable energy development in Nigeria. In Nigeria, the reliance on fossil fuels for energy generation has led to energy insecurity, environmental degradation, and economic challenges. Despite the abundance of solar resources, the adoption of solar energy and building integration technology in residential buildings remains limited due to various barriers, including high upfront costs, lack of public awareness, and inadequate policy and regulatory frameworks (Obodoh et al, 2024). As a result, Nigeria's energy sector continues to face significant challenges, including:

- Energy access disparities
- Environmental concerns
- High energy costs
- Limited energy efficiency
- Inadequate building design and construction practices

The country faces significant energy challenges, including: (i) Energy access disparities: Over 80 million Nigerians lack access to electricity, relying on hazardous and expensive alternative sources. (ii) Environmental concerns: The country's reliance on fossil fuels contributes to climate change, air pollution, and environmental degradation. (iii) High energy costs: Energy expenditures burden households and businesses, hindering economic development. (iv) Limited energy efficiency: Inefficient energy use and wastage characterize Nigeria's energy sector. (v) Inadequate building design and construction practices: Buildings are often designed and constructed without consideration for energy efficiency or renewable energy integration.

Solar energy offers a promising solution, but its adoption in Nigerian residential buildings is limited (Obodoh et al, 2024). Building integration technology can enhance solar energy efficiency, but its application is not well understood in the Nigerian context.

This study aims to investigate the opportunities and challenges associated with harnessing solar energy and building integration technology in Nigerian residential buildings, in order to identify solutions that can address these challenges and promote sustainable energy development in Nigeria.

II. SOLAR ENERGY POTENTIAL

The integration of solar energy and building integration technology in residential buildings has gained significant attention in recent years, particularly in regions with high solar irradiance like Nigeria. Nigeria receives an average daily solar radiation of 5.5 kWh/m², making it an ideal location for solar energy harnessing (Sambo, 2019). Building integration technology can improve solar energy efficiency by up to 30% (Kumar et al., 2019). Optimal building design and orientation are crucial for effective solar energy absorption (Adebayo et al., 2020).

Solar energy systems can reduce energy costs by up to 70% in Nigerian residential buildings (Adewuyi et al., 2017). Energy-efficient buildings with integrated solar energy systems can achieve significant energy savings (Ogueke et al., 2020).

Effective policy and regulatory frameworks are essential for promoting the adoption of solar energy and building integration technology (Akinyele et al., 2020). Nigeria's renewable energy policy aims to increase solar energy contribution to 30% of the energy mix by 2030 (Federal Government of Nigeria, 2020).

High upfront costs, lack of public awareness, and limited financing options are significant barriers to the adoption of solar energy and building integration technology in Nigeria (Akinbami et al., 2019).

In recent years, there has been an increase in the development of building façades with a focus on strategic development. - The building façade plays a crucial role in the engineering and architecture of a building. - The integration of renewable energy, especially solar energy, into building facades has a significant impact on the comfort of the building's occupants, the building's energy needs and the building's aesthetic appeal. - There are three categories of building integrated solar energy systems (BI-SES) for facades: thermal, photovoltaic and hybrid (thermal and photovoltaic). - The scientific community and policymakers are working together to develop and implement innovative solutions and regulations to address the challenges faced by the building sector. - The Energy Performance of Buildings Directive (EPBD) aims to achieve environmental and energy efficiency goals by adopting the nearly Zero Energy Buildings (nSEB) performance for new and existing buildings For a building to be considered nZEB, it must reduce its energy consumption and generate energy from renewable sources to compensate for the majority of the building’s consumption while maintaining thermal comfort. The integration of renewable systems in buildings is usually done in the building envelope (walls and roofs). The building façade elements can improve the energy flexibility of the building by adapting to different boundary conditions and climate. Building integrated photovoltaic system (BIPV) is a complex system that is difficult to adapt to the improvement of energy performance. There is a trade-off between life cycle assessment and real improvement in energy demand reduction.

III. APPLICATION OF SOLAR ENERGY AND BUILDING INTEGRATION TECHNOLOGY IN RESIDENTIAL BUILDING

The application of solar energy and building integration technology in residential buildings, mainly has three aspect: solar thermal technology, solar photovoltaic technology, solar optical technology, and mainly set on roofs, balconies, exterior walls and somewhere with ample sunshine.

Solar photovoltaic systems

Solar photovoltaic (PV) systems directly convert solar energy to electrical energy by means of semiconductors in photovoltaic cells (Kadir et al. 2010; Mekhilef et al. 2011). Residential solar panels can be installed on the rooftop, either stand-alone or grid- connected (Muhammad-Sukki et al. 2011) (Figures 4 & 5).

Figure 5: a) Roof layout of solar PV system and b) grid connected solar PV system

Fig 4. Scheme of a common grid connected roof integrated PV installation

Solar photovoltaic (PV) systems have the largest potential as a renewable energy source in Malaysia due to the country's location benefiting from sunlight abundance (Rahim and Hasanuzzaman, 2014). With a daily radiation of four to eight hours, the average annual irradiance is around 1,600 kWh/m². Solar energy development was at 1 MW as of 2011, where it could potentially reach higher than 6,500 MW (Ahmad et al. 2014). Solar intensity is highest at the northern region and gradually decreases to the south, which makes the northern region of Malaysia an ideal location to invest in solar energy (Abdullah et al. 2019). Grid connected PV systems are connected to the local utility grid. These PV systems produce electricity using solar energy and during cloudy days or at night (when there is no excess electricity) electricity can be obtained from the grid network. The excess energy can also be sold (under the FiT mechanism) to the electric distribution company. Solar PV systems have many advantages. The process of producing electricity is clean and noiseless since the technology does not require burning or physical conversion of the solar energy. According to Oh et al. (2010), 1 MW of electricity produced by a solar PV system is equal to 4 MW generated by conventional electricity. Because in a PV system electricity is produced in the place where it is needed, transmission losses can be avoided (Beccali et al. 2013).

- Thermal Technology

In thermal it is mainly used to supply domestic hot water heating etc. Designing of the integration of solar hot water system and residential buildings improve the form of the system itself. Traditional solar hot water system cannot meet the need of solar energy integration in building either in quality or in performance .To meet the hot water needs installation area is correspondingly increased, hot water is not just use for bath, used for heating and supplying domestic water. Integrating solar collector with the roofs, balcony rails of the south façade, bay windows and walls, can make the appearance of residential buildings be overall unified. When installed on the flat roof, the flat-plate solar collector can act as roof covering or insulation layer and investment and reduce the cost. Glazed flat plate collectors are used in space heating (figure 1) They usually consist of 10 cm thick rectangular boxes of about 2 m2, containing several layers. Unglazed flat plate collectors are used for low temperature space heating systems and made of a selective metal plate and a hydraulic circuit connected to this absorber (figure 2). Working temperature is 50-65°C. Evacuated tube collectors are especially recommended for applications requiring high working temperatures such as industrial applications and also used for domestic hot water production and space heating (figure 3). They are made of several individual glass tubes, each containing an absorber tube. The very high insulation power of the vacuum allows reaching very high temperatures (120-180°C) (Wang, 2010, Wang, 2008).


Fig 1.Glazed flat plate collector

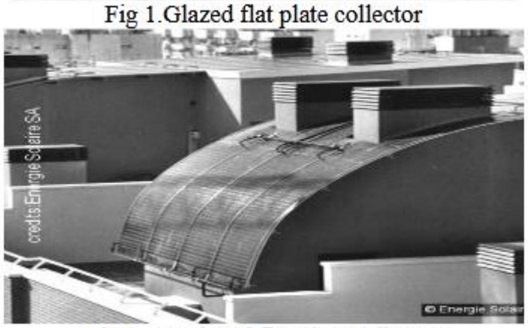

Fig 2. Unglazed flat plate collector


Fig 3. Vacuum tubes collector

Optical Technology
Recently, energy and environmental concerns have made day lighting a rediscovered aspect of building lighting design. Day lighting is often integrated into a building as an architectural statement and for energy savings. The idea of piping light from a remote source to an interior space for illumination purpose appeared about 120 years ago light pipe is now being adopted and applied world widely for both artificial and natural day lighting purposes. With the increasing use of solar light pipes, more attention is being paid to their development, especially to the day lighting performance evaluation of the device

They generally have three main components, namely the daylight collecting device, daylight transmitting device and daylight emitting device. Optcal technology in residential buildings is for lighting, natural light can enter into the function rooms through the light guide tube, thus improve the indoor day lighting situation, such as underground garage, equipment room and storage room. The light guide tube is mainly composed of three parts: a light collector for collecting the daylight; tubing portion for transmitting light; the light exit portion for controlling the distribution of the light in the room (figure 5) Main components of light pipe are described below (Xu, 2012, Qin,1986)


Fig 5. Solar optical system on the roof

IV. CHALLENGES IN THE IMPLEMENTATION OF SOLAR ENERGY IN NIGERIA

Even though, Nigeria possesses potential driving factors for solar energy players to promote the initiatives throughout the country, the deployment and implementation of the initiatives still faces major obstacles making the implementation very challenging (Maka et al, 2021). It is hoped that the private sector participation will help the government to come out with an achievable solar energy roadmap. Some of the challenges include:

- Nigeria faces energy access disparities and environmental challenges.
- The geographical diversity of Nigeria's climates necessitates versatile solar energy solutions capable of thriving in a wide range of conditions.
- The nation's energy mix has historically relied heavily on fossil fuels, particularly crude oil, which exposes Nigeria to the volatility of global oil markets.

- The energy demand continues to surge, and the country has recognized the imperative to diversify its energy mix and reduce its carbon footprint.
- Lack of training facilities and entrepreneur's development mechanism,
- lack of political will to diversify into clean energy
- Lack of access to capital, credit to consumers and financial instrument
- Grid unreliability
- Government policy (inconsistency)

V. OPPORTUNITIES IN THE IMPLEMENTATION OF SOLAR ENERGY IN NIGERIA

Beside the location of Nigeria on a belt where solar radiation is high, there are other factors which help in driving the opportunity for the deployment of solar energy initiative in the country and these include:

- Solar energy stands as a transformative force in addressing Nigeria's energy needs while mitigating the effects of climate change.
- Solar technologies are versatile and adaptable to different climate conditions.
- Technological innovation, policy alignment, and capacity building address challenges such as intermittency, climate-related factors, and upfront costs.
- Solar energy has the potential to revolutionize the energy landscape in Nigeria.
- The promotion of solar energy in Nigeria will contribute enormously to poverty reduction by engaging young people in local communities to participate and benefit from the opportunity in skills development, technology transfer and investment opportunities (Darman, et al. 2014). Many alternative energy pilot projects in developing countries give positive evidence of impact on socioeconomic development, especially the rural communities in Nigeria with abundant, natural resources Ohunakin, et al. 2014). The increase in the investment in the solar battery manufacturing, installations, maintenance and repair skills, and the manufacture of various solar devices leads to the creation of massive job opportunities.
- Solar and other renewable energy projects cannot succeed without the intervention of local stakeholders. When local entrepreneurs, explicitly integrates their investment towards solar energy technology, the success of the technology is achievable (Zahedi, 2011; Marques and Fuinhas, 2011. Therefore, local investors, entrepreneurs and end users are encouraged to fully participate in the promotion, generation, production and implementation of solar energy in Nigeria to help mitigate the appalling electricity shortage in the country (Ohunakin, et al 2014)

VI. THE ROLE OF SOLAR ENERGY IN SUSTAINABLE DEVELOPMENT

Sustainable energy development is defined as the development of the energy sector in terms of energy generating, distributing and utilizing that are based on sustainability rules (Radovanovic et al, 2012). Energy systems will significantly impact the environment in both developed and developing countries like Nigeria. Consequently, the global sustainable energy system must optimize efficiency and reduce emissions (Salvarili et al, 2020).

The sustainable development scenario is built based on the economic perspective. It also examines what activities will be required to meet shared long-term climate benefits, clean air and energy access targets (Ali and Jamal 2022). The short-term details are based on the International Energy Agency's (IEA's) sustainable recovery strategy, which aims to promote economies and employment through developing a cleaner and more reliable energy infrastructure (Cozzi et al, 2020). In addition, sustainable development includes utilizing renewable-energy applications, smart- grid technologies, energy security, and energy pricing, and having a sound energy policy (Salvarili, 2020).. The demand-side response can help meet the flexibility requirements in electricity systems by moving demand over time. As a result, the integration of renewable technologies for helping facilitate the peak demand is reduced, system stability is maintained, and total costs and CO_2 emissions are reduced. The demand-side response is currently used mostly in Europe and North America, where it is primarily aimed at huge commercial and industrial electricity customers (Radovanovic et al, 2012). International standards are an essential component of high-quality infrastructure. Establishing legislative

convergence, increasing competition and supporting innovation will allow participants to take part in a global world PV market Maka et al, 2021).. Numerous additional countries might benefit from more actively engaging in developing global solar PV standards. The leading countries in solar PV manufacturing and deployment have embraced global standards for PV systems and highly contributed to clean-energy development. Additional assistance and capacity-building to enhance quality infrastructure in developing economies might also help support wider implementation and compliance with international solar PV standards. Thus, support can bring legal requirements and frameworks into consistency and give additional impetus for the trade of secure and high-quality solar PV products (Gahrens et al, 2021)
Continuous trade-led dissemination of solar PV and other renewable technologies will strengthen the national infrastructure. For instance, off-grid solar energy alternatives, such as stand-alone systems and mini-grids, could be easily deployed to assist healthcare facilities in improving their degree of services and powering portable testing sites and vaccination coolers. In addition to helping in the immediate medical crisis, trade-led solar PV adoption could aid in the improving economy from the COVID-19 outbreak, not least by providing jobs in the renewable-energy sector, which are estimated to reach >40 million by 2050 (Gahrens et al 2021).

The framework for energy sustainability development, by the application of solar energy, is one way to achieve that goal. With the large availability of solar energy resources for PV and Concentrated Solar Power (CSP) energy applications, we can move towards energy sustainability. Fig. 3 illustrates plans for solar energy sustainability (Ali and Jamal. 2022)

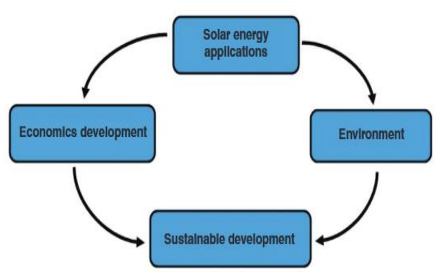

Fig. 3: Framework for solar energy applications in energy sustainability.

The environmental considerations of such applications, including an aspect of the environmental conditions, operating conditions, etc., have been assessed. It is clean, friendly to the environment and also energy-saving. Moreover, this technology has no removable parts, low maintenance procedures and longevity. Economic and social developments are considered by offering job opportunities to the communities and providing cheaper energy options. It can also improve people’s income; in turn, living standards will be enhanced. Therefore, energy is paramount, considered to be the most vital element of human life, society’s progress and economic development.

As efforts are made to increase the energy transition towards sustainable energy systems, it is anticipated that the next decade will see a continued booming of solar energy and all clean-energy technology in Nigeria.. Scholars worldwide consider research and innovation to be substantial drivers to enhance the potency of such solar application technology.

VII. CONCLUSION AND RECOMMENDATIONS

The study reveals that harnessing solar energy and building integration technology in Nigerian residential buildings presents vast opportunities for sustainable energy generation, reduced energy costs, and mitigated environmental impact. However, challenges such as high upfront costs, lack of policy support, and limited public awareness hinder widespread adoption. Addressing these challenges is crucial to unlocking the full potential of solar energy and building integration technology in Nigeria's residential sector. The study therefore recommends the following:

1. Government incentives: Offer tax credits, subsidies, and low-interest loans to encourage adoption.
2. Policy framework: Develop and implement policies supporting renewable energy integration.
3. Public awareness: Educate homeowners and builders about benefits and feasibility.
4. Research and development: Collaborate with industry and academia to improve technology and affordability.
5. Financing options: Explore innovative financing models for homeowners and developers.

6. Building codes and standards: Incorporate solar energy integration into building regulations.
7. Training and capacity building: Develop skills and expertise in solar energy installation and maintenance.
8. Pilot projects: Demonstrate successful integration in showcase projects to build confidence.
9. By addressing these recommendations, Nigeria can harness solar energy and building integration technology to create a sustainable, energy-efficient, and environmentally friendly residential building sector.

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