



PROSPECTS, CHALLENGES AND OPPORTUNITIES IN THE DEPLOYMENT OF SOLAR PHOTOVOLTAICS IN DEVELOPING COUNTRIES

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<https://doi.org/10.5281/zenodo.17932622>

https://njrer.org/download/prospects,_challenges_and_opportunities_in_the_deployment_of_solar_photovoltaics.pdf

ARTICLE INFORMATION

Article history:

Received 19 Jun., 2025

Revised 25 Sep., 2025

Accepted 27 Oct., 2025

Available online 30 Nov., 2025

Keywords:

solar photovoltaic, developing nations, renewable energy, energy accessibility, environmental advantages, technology advancements, constraints.

ABSTRACT

The rising worldwide energy demand and the pursuit of sustainable development have resulted in the use of solar photovoltaic (PV) technology as a viable alternative. Developing nations, facing various challenges and ambitions, are at a critical crossroads where the adoption of solar photovoltaic technology might instigate significant transformation. This study examines the implementation of solar photovoltaics in developing nations, focussing on the associated problems and potential. This study examines the status of solar photovoltaic technology, the challenges it faces in developing nations, and the potential opportunities and uses. Developing countries are poised for a significant opportunity in the shift to sustainable energy. International assistance, encompassing loans, grants, technical support, and collaborative partnerships, serves as a beacon of hope, igniting the impetus necessary to promote the use of solar photovoltaic (PV) technology. The essential function of international collaboration in advancing solar energy deployment, based on case studies that illustrate the capacity for cooperative initiatives to accelerate development and foster a cleaner, more equitable energy landscape. Nigeria energy landscape is unpredictable and unreliable and so the deployment of renewable energy can ensure constant energy supply. Tanzania exemplifies how the desire for energy solutions may stimulate innovation. Haiti, a nation grappling with energy poverty, exemplifies the necessity of international collaboration for sustainable development. The Solar Market Gardens initiative was initiated by the Solar Electric Light Fund (SELF) in partnership with local organisations and international financiers. This initiative enhanced agricultural output in Nigeria.

1. INTRODUCTION

The investigation of renewable energy sources has become an essential pursuit in an age marked by a continuous increase in global energy consumption and a pressing need for sustainable development (Kenu, 2020). Solar photovoltaic (PV) technology has emerged as a promising alternative, poised to transform the energy landscape with its abundant and environmentally friendly characteristics (Nimay et al., 2021). This paper explores the captivating realm of solar PV adoption, focussing on its advantages and problems for poor countries (Carvalho, 2021).

The significant increase in global energy consumption poses a serious concern for both the present and future (Pratish, 2021; Dania, 2020). This insatiable demand for energy, primarily driven by limited fossil fuel reserves, fosters economic growth while underscoring the essential need for energy diversification. Simultaneously, the demands of sustainable development, echoing through international channels, necessitate a departure from the established carbon-intensive path (Haris and Sarwar, 2013).

Figure 1 illustrates the two categories of energy sources: renewable and non-renewable energy. The global shift away from non-renewable energy sources, such as petroleum (Ukoba et al., 2011), is driven by their contribution to greenhouse gas emissions that exacerbate global warming. Renewable energy serves as a crucial lifeline at this critical moment, with solar photovoltaic technology assuming a dominant role. Additional forms of renewable energy encompass wind (Ukoba et al., 2023), hydro (Adhikari et al., 2023), and biomass (Imoisili et al., 2014).

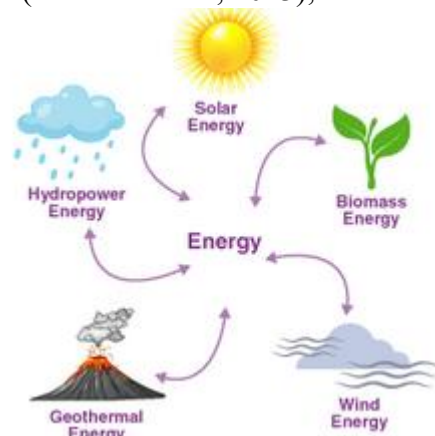


Figure 1. Sources of energy

2. SOLAR PHOTOVOLTAIC TECHNOLOGY

Photovoltaics, sometimes abbreviated as PV, derives its name from the process of turning light (photons) into electricity (voltage), known as the photovoltaic effect. Solar photovoltaic technology, predicated on the principle of converting sunlight directly into electricity, possesses an unmistakable allure. There are three primary categories of solar photovoltaic systems: grid-tied, hybrid, and off-grid. Every category of solar panel system possesses distinct advantages and disadvantages, ultimately depending on the customer's objectives for their solar panel installation.

Figure 2 illustrates thin film, monocrystalline, and polycrystalline solar panels. Solar photovoltaic systems typically comprise six distinct components: the solar PV array, a charge controller, a battery bank, an inverter, a utility meter, and an electric grid. The proper installation of all

components dictates the efficiency of the solar system solution. Solar energy can be categorised into two classifications based on the conversion method and the type of energy produced. Passive solar energy and active solar energy pertain to the methods of conversion, including solar thermal energy, photovoltaic solar power, and concentrating solar power.

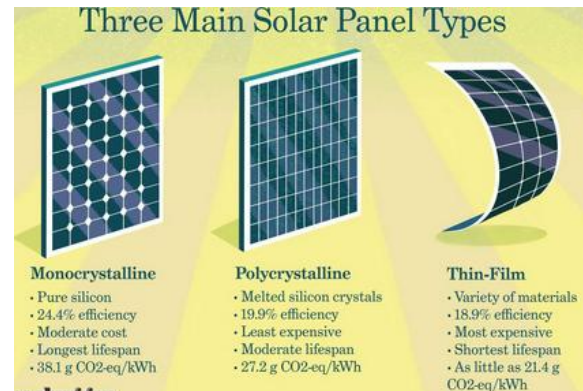


Figure 2. Categories of Solar Photovoltaic Systems

This technology holds significant potential in the sunlit regions of developing nations (Abdelrazik et al., 2022), heralding a new era of energy production. The inherent availability of solar radiation in these regions signifies the potential for energy democratisation, liberating marginalised communities from the limitations of energy poverty (Shafqat et al., 2018). Remote communities and urban slums can both benefit from electrification, igniting progress and enhancing human welfare with the sun as a universal ally.

The environmental significance of solar photovoltaic technology cannot be overstated. Its operation is remarkably discreet, generating no emissions while alleviating the suffering of the planet. As developing nations endeavour to circumvent the detrimental growth trajectories of their industrialised counterparts, solar photovoltaic technology emerges as an essential instrument (Nogin et al., 2023). This technology exemplifies responsible development, ensuring that the quest for prosperity does not adversely affect the fragile ecosystems that support life (Wyllie et al., 2018).

Developing nations are essential to the transition in the possibilities offered by solar photovoltaic technology. Countries like South Africa have commenced the implementation of solar photovoltaic systems for power generation in both rural and urban areas, as illustrated in Figure 3.

The intersection of three crucial elements—energy deprivation, carbon output, and economic progress—renders solar PV implementation a highly advantageous pursuit. The memoirs of energy poverty are characterised by themes of despair—communities languishing in darkness, lacking fundamental comforts and opportunities (Victoria et al., 2021). Nevertheless, amidst this sorrow, solar photovoltaic technology emerges as a beacon of optimism. Its decentralised nature facilitates the establishment of microgrids that traverse hazardous landscapes, illuminating lives and fostering developmental progress (Islami et al., 2021; Yoldaş et al., 2017).



Figure 3. A solar panel on a rooftop in a Nigerian House

The issue of carbon emissions, which pervades the global climate change discourse, is countered by solar photovoltaic technology. As these nations navigate the delicate balance between development and environmental conservation, solar photovoltaic technology emerges as a viable answer, enabling a reduction in carbon emissions without hindering progress. Moreover, the allure of economic growth, which serves as the foundation for the objectives of emerging nations, has unexpectedly aligned with solar photovoltaic technology. The capacity for job creation along the value chain, encompassing production, installation, and maintenance, redefines the parameters of prosperity (Bunda et al., 2023).

Moreover, significant solar PV implementation is accompanied by a multitude of challenges that require advanced solutions. Underdeveloped nations face considerable financial constraints, making the substantial initial expenses of solar systems a notable impediment (Varun et al., 2016). Moreover, the deficient grid infrastructure, characterised by fragility and volatility, necessitates substantial enhancements to support the influx of solar energy. Another concern is the complexity of regulations and procedures, which requires coordinated efforts to create an environment conducive to solar investment. Moreover, an absence of technical skills engenders a dire circumstance, underscoring the necessity for capacity-building to effectively harness solar potential (Wim and Smeets, Anse, 2022).

Nonetheless, the realm of solar PV development in developing countries is an enticing area where potential and challenges intertwine intricately. The context of this narrative encompasses the escalating global energy need, the necessity for sustainable development, and the transformative potential of solar photovoltaic technology. This article will elucidate the array of challenges that obscure this promise, intertwined with the vibrant opportunities that serve as navigators towards a more sustainable future.

In the initial phases of solar PV adoption, financial obstacles hinder extensive implementation. Resource limitations, infrastructural limits, and policy and regulatory impediments complicate solar PV implementation. Instances from Sub-Saharan Africa, the Caribbean, and South Asia illustrate hybrid solutions, intelligent grid systems, and microgrids that surmount infrastructural constraints.

Policy and regulatory impediments exacerbate the challenges of solar PV implementation. Private investments may be hindered by erratic legislation, bureaucratic obstacles, and an absence of enabling frameworks. Nonetheless, unequivocal and consistent regulatory frameworks are essential for the advancement of solar energy. Adequate technical expertise is essential for the effective design, installation, and maintenance of solar photovoltaic systems. The trajectory of solar photovoltaic adoption is significantly shaped by perception and awareness. Misunderstandings regarding the reliability, cost, and advantages of solar energy might hinder progress. Solar photovoltaic technology enhances energy accessibility, fosters employment growth, provides environmental benefits, stimulates technological innovation, and promotes global cooperation. It delivers dependable power to remote and underprivileged regions using decentralised solutions, off-grid technologies, and innovative financial structures, thereby enhancing education, healthcare, and overall well-being. Technological innovation is fundamental, illustrating how the constraints of solar adoption catalyse creative solutions. Localised technologies, smart grids, and microgrids are transforming energy landscapes, especially in regions with varied energy requirements. International assistance through grants, loans, technical support, and partnerships offers crucial support to developing nations striving to implement solar energy.

The transition to solar PV adoption in developing nations is characterised by a myriad of challenges, opportunities, and ambitions. This study explores various financial limitations, infrastructure challenges, policy obstacles, technical skill deficiencies, and perception problems, illustrating solar energy's transformative potential in terms of energy accessibility, employment generation, environmental conservation, technological advancement, and global support. The adoption of solar PV serves as a beacon, guiding the development of resilient, empowered, and equal societies in the developing countries.

2.1 Current Position of Solar Photovoltaics

The ultimate goal of green economy advocates is for solar photovoltaic technology to supply energy to nearly the whole globe, as illustrated in Figure 4.

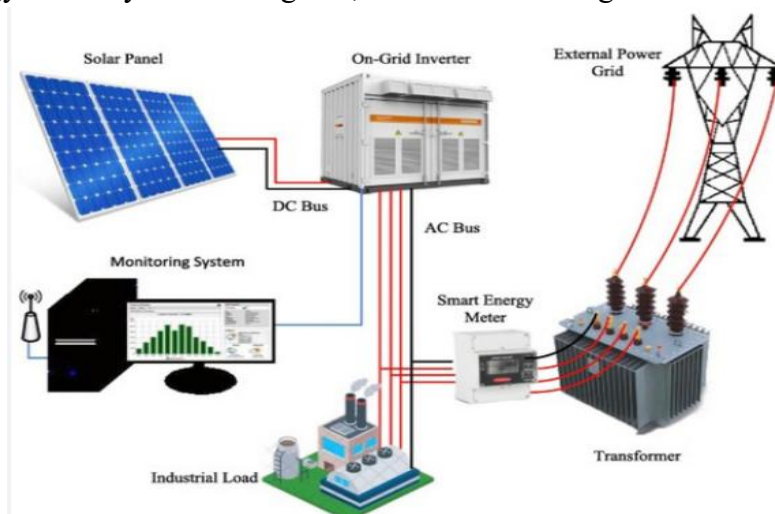


Figure 4. Application of solar photovoltaic technology for worldwide electricity production

Solar photovoltaic (PV) technology has undergone significant metamorphosis, transcending borders and altering energy landscapes globally. In the context of global challenges related to sustainable development and climate action, the status of solar photovoltaic technology stands as a symbol of optimism, reflecting both current advancements and the potential for significantly greater future accomplishments. The utilisation of solar photovoltaic technology has undergone a significant transformation in the past twenty years, evolving from a peripheral innovation to a global leader. Solar panels have first been implemented on rooftops, commercial edifices, and utility-scale installations in industrialised countries. Countries including Germany, China, the United States, and Japan have demonstrated the viability of solar energy and established a framework for developing nations to emulate (Usha and Douglas, 2011).

The status of solar photovoltaic technology is not exclusive to wealthy economies. Developing nations have enthusiastically entered the competition, driven by abundant sunlight and increasing energy requirements (Jacob, 2016). The spread of solar PV in these nations is driven by a confluence of factors, including energy access needs, economic growth objectives, and commitments to environmental stewardship. These nations are increasingly embracing solar energy to bridge energy deficits, generate employment, reduce carbon emissions, and foster technological innovation. A notable attribute of contemporary solar PV is its capacity to foster equal growth. Solar microgrids, off-grid systems, and innovative financing techniques are enhancing isolated villages, empowering individuals, and advancing education, healthcare, and overall quality of life. The integration of solar energy and technology is generating solutions that extend beyond energy accessibility, facilitating economic development while enhancing environmental sustainability (Hashwini et al., 2021).

The future of solar PV is poised for a significant transformation. The effectiveness and cost of solar panels are always enhancing due to technological advancements, rendering them increasingly accessible. Energy storage solutions, along with advancements in battery technology, are addressing the intermittency challenge, ensuring that solar energy remains reliable even post-sunset (Mehdi et al., 2023). Smart grids, Internet of Things (IoT) connection, and decentralised energy systems indicate a future where solar energy might power not only individual homes but perhaps entire cities. The global commitment to combat climate change is elevating solar PV to prominence. International coalitions, shown as the International Solar Alliance, illustrate the worldwide commitment to advancing solar energy utilisation. Financing mechanisms and regulatory frameworks are being enhanced to facilitate solar initiatives in underdeveloped countries, reflecting an increasing recognition of solar energy's potential to advance global sustainable development.

The status of solar photovoltaic technology is at a pivotal juncture of advancement and potential. Developed nations have established the foundation, but underdeveloped countries perceive solar energy as a transformative force. The modern environment is characterised by technical progress, inclusive growth, and international partnerships, indicating a future where solar photovoltaic technology becomes a transformative influence, leading us towards a more sustainable, egalitarian, and empowered society.

2.2 Challenges of Solar Photovoltaics deployment in Developing Nations

The transition to solar photovoltaic (PV) technology in underdeveloped nations is indeed beset with challenges, with financial limitations being among the most formidable. The substantial initial expense of installing solar photovoltaic systems constitutes a significant barrier to the extensive adoption of this promising renewable energy source. Developing nations often face fiscal limitations, prioritising essential areas such as healthcare, education, and infrastructure. Consequently, allocating substantial funds for solar PV installations presents a formidable challenge.

The capital required for solar panels, inverters, and energy storage systems, while offering potential long-term advantages, presents a substantial initial expense for several individuals and governments (Moner-Girona et al., 2021). India exemplifies the financial challenges linked to the use of solar photovoltaic technology. Notwithstanding its ambitious solar objectives and extensive solar potential, the country has encountered obstacles due to fiscal constraints. The Indian solar sector heavily depended on external funding during its initial stages, as domestic financial institutions were reluctant to invest in unproven technology. The establishment of initiatives like the International Solar Alliance aims to consolidate resources and use economies of scale to reduce expenses, highlighting the collaborative strategy necessary to surmount financial challenges (Oguntuase, 2022). Bangladesh serves as another compelling illustration. The nation sought to enhance power accessibility in remote areas via its robust solar home system initiative. Notwithstanding its success, the initial investment continued to pose a challenge for numerous low-income households.

To mitigate this issue, innovative financing alternatives such as pay-as-you-go systems and microloans were implemented, enabling families to get solar energy without bearing the entire financial obligation initially. A comparable narrative is unfolding in Kenya. The elevated expense of solar systems has deterred numerous individuals from embracing the technology. Consequently, mobile payment networks facilitated the creation of pay-as-you-go models, enabling homeowners to finance their solar systems incrementally over time. This innovative strategy circumvented substantial initial costs and facilitated increased solar PV deployment, thereby enhancing energy access and fostering economic growth (Adwek et al., 2020).

The prohibitive expense of solar PV installation in developing countries constitutes a major obstacle to broader implementation. The experiences of these developing nations illustrate that innovative financial strategies, cooperative initiatives, and targeted interventions can effectively address these financial limitations (Mehdi et al., 2023). As these nations navigate their paths towards sustainable energy futures, innovation, resourcefulness, and strategic partnerships become essential allies in actualising the transformative potential of solar photovoltaic technology.

A significant obstacle to the seamless integration of solar photovoltaic (PV) systems in developing nations is the inadequate infrastructure. The nascent state of grid infrastructure, coupled with erratic power supply and inadequate storage capacity, undermines the feasibility of solar arrays. Sub-Saharan Africa exemplifies the significant infrastructural challenges that can impede solar PV implementation. The region faces challenges due to insufficient grid infrastructure, rendering the integration of intermittent solar power sources a formidable task. Nigeria faces the challenge of unreliable electrical supply due to outdated and insufficient grid infrastructure. This deficiency

hinders the seamless incorporation of excess solar energy into the grid, diminishing the advantages of solar systems and obstructing efforts to electrify rural areas (Nwaigwe et al., 2019). Haiti, situated in the Caribbean, possesses a comparable narrative. The nation's energy landscape is defined by fragile and inefficient grid systems. Despite the potential of solar PV projects, the lack of contemporary infrastructure hinders the effective integration of surplus energy into the grid (Keston, 2020).

This constraint underscores the intricate relationship between solar adoption and the pressing necessity for substantial grid enhancements. Notwithstanding its effective solar home system initiative, Bangladesh faces infrastructural challenges. The limited storage capacity of batteries is a significant challenge in rural areas where solar household systems are expanding. Consequently, solar energy remains underexploited, and its potential productive applications are impeded. To address this challenge, innovative strategies such as the implementation of energy-efficient appliances and localised microgrids have emerged, enabling communities to optimise the advantages of solar energy while navigating the limitations of inadequate infrastructure. The lack of infrastructure in developing countries hinders the effective integration of solar PV systems, necessitating the management of the intricate relationship between solar technology and the infrastructure reliant on its efficacy.

The implementation of solar photovoltaic (PV) technology in underdeveloped nations is impeded by governmental and regulatory barriers. The intricate web of conflicting regulations, onerous bureaucratic processes, and absence of conducive regulatory frameworks may undermine the potential of solar energy. Nigeria exemplifies the detrimental effects of regulatory ambiguity. The country's energy sector is governed by a complex array of regulations that allow for interpretation and create ambiguity. Consequently, prospective investors in solar projects are sometimes trapped in a maze of conflicting regulations and ambiguous administrative procedures (Haris and Sarwar, 2013). The absence of legislative clarity hinders private investment and obstructs the growth of solar PV, hampering Nigeria's advancement towards a sustainable energy future.

Conversely, Chile demonstrates the transformative effects of advantageous policy frameworks. The nation's Renewable Portfolio Standard (RPS) mandates a specified quantity of energy to be derived from renewable sources, including solar photovoltaic (PV) systems. This coherent and uniform policy not only attracted significant private investment but also propelled Chile to the vanguard of solar energy development (Chiara and Francesca, 2021). The implementation of open regulations and progressive policies fostered an environment that promoted innovation, increased investment, and expedited solar PV expansion. A further compelling illustration is the United Arab Emirates (UAE). In an area traditionally dependent on fossil resources, the UAE implemented stringent rules that facilitated the adoption of renewable energy, especially solar photovoltaic technology. The UAE created a dependable revenue source for investors by implementing feed-in tariffs and power purchase agreements (PPAs) with fixed price for solar energy, facilitating rapid growth in the solar industry. This proactive policy approach transformed the country's energy sector and illustrates the transformative potential of supportive regulations (Kılıç and Kekezoğlu, 2022). Even within a same nation, varying regulatory frameworks may yield divergent outcomes. Gujarat, India, has become a solar powerhouse, partly due to assertive legislative measures. Gujarat attracted substantial private investment and emerged as a leader in solar energy production by offering appealing incentives, streamlined approvals, and a conducive environment for solar

project development. This underscores the vital importance of policy in influencing solar PV development trajectories, in contrast to other Indian states with less favourable regulatory frameworks.

The intricate web of political and regulatory challenges constitutes a significant impediment to the widespread use of solar PV technology in developing countries. A stable, open, and supportive legislative environment could be the catalyst for solar PV adoption, drawing private investment and facilitating sustainable energy transitions. As these nations navigate the delicate equilibrium between developmental necessities and regulatory transparency, they encounter a pivotal juncture towards a cleaner, more sustainable energy future.

Moreover, a significant barrier to the extensive use of solar photovoltaic (PV) technology in poor countries is the deficiency of technical expertise. The intricate process of developing, building, and maintaining solar PV systems requires trained specialists and technicians. A deficiency in these abilities significantly hinders the effective execution of solar projects. Sub-Saharan Africa illustrates the repercussions of insufficient technological expertise. The region's ability to effectively harness the vast potential of solar energy is hindered by a deficiency of skilled professionals. Tanzania is experiencing a deficiency of skilled solar professionals. Consequently, system installations are inefficient, system longevity is diminished, and maintenance practices are inadequate. This information deficit hinders both energy accessibility and the sustained profitability of solar photovoltaic systems (Jacob, 2016).

The main challenges for renewable energy deployment in Nigeria include high upfront costs and a lack of affordable financing, inconsistent and inadequate policies, and insufficient infrastructure for integration into the grid. Other significant barriers are limited domestic manufacturing capacity, a lack of skilled technical expertise, and weak institutional capacity, which together slow down project execution.

2.3 Financial and economic barriers

- *High upfront costs:* The initial cost of renewable energy systems like solar panels is a major obstacle for many households, particularly in rural areas.
- *Limited access to financing:* There is a scarcity of capital investment, with high interest rates from commercial banks and a lack of affordable, long-term financing options.
- *Low foreign investment:* Perceived risks related to policy inconsistency, currency volatility, and the overall macroeconomic environment deter foreign direct investment.

2.4 Policy and regulatory issues

- *Inconsistent and weak policies:* There is a lack of clear, consistent, and harmonized policies, which hinders implementation and creates uncertainty for investors and stakeholders.
- *Inadequate legal framework:* The legal and regulatory frameworks are insufficient, with weak enforcement mechanisms.
- *Government support distortion:* Subsidies for fossil fuels have historically created a disincentive for renewable energy, although this is changing.

2.5 Infrastructure and technological limitations

- *Inadequate grid infrastructure:* The existing power grid is often outdated, congested, and fragile, making it difficult to integrate new renewable sources.
- *Lack of transmission and distribution:* There is a lack of the necessary infrastructure for transmitting and distributing power from renewable sources.
- *Limited domestic manufacturing:* Nigeria lacks a robust domestic manufacturing capacity for renewable energy components, forcing most to be imported, which increases costs.

2.6 Human and institutional challenges

- *Lack of technical expertise:* There is a shortage of skilled technical personnel, both in the private sector and within government agencies, to effectively manage and oversee projects.
- *Weak institutional capacity:* Fragmented governance and a lack of coordination between government bodies create bureaucratic bottlenecks and inefficiencies.
- *Limited awareness:* There is a need for greater awareness of the benefits of renewable energy at both the individual and institutional levels.

Bangladesh offers an alternative viewpoint on this matter. The scarcity of competent labour was a barrier when the nation sought to implement rural electrification via solar household systems. Owing to a scarcity of experts proficient in addressing technical challenges and delivering maintenance, installed systems were underutilised, resulting in an incomplete realisation of solar energy benefits. The necessity of investing in capacity building became evident as the demand for skilled human resources became apparent (Amit et al., 2022). The International Solar Energy Society (ISES) has recognised a prevalent issue in numerous developing nations: a lack of specialised training programs and educational initiatives to foster solar expertise. The absence of comprehensive training not only constrains the advancement of solar workers but also sustains a cycle of underdeveloped solar projects.

Conversely, Morocco exemplifies progress in bridging the technical competence gap. The country acknowledged the necessity of cultivating a skilled solar workforce as it initiated substantial solar projects such as the Noor Ouarzazate Solar Complex. Morocco established training programs and knowledge-sharing initiatives in partnership with international entities and organisations. These programs empowered Moroccan technicians and engineers, facilitating the successful completion of large-scale solar projects and establishing Morocco as a leader in solar energy development.

The deficiency of technical skills constitutes a significant obstacle to solar PV advancement in poor nations. As nations navigate the challenges of solar technology implementation, investing in skilled personnel acts as a beacon, illuminating the path towards sustainable energy futures and ensuring the long-term success of solar photovoltaic projects.

An unseen yet formidable barrier to the adoption of renewable energy, especially in developing countries, is perception and knowledge. In contrast to conventional energy sources, the feasibility of solar energy as an alternative may be hindered by insufficient awareness of its advantages or misconceptions regarding its reliability and cost (Bernadette and Michael 2016). Pakistan serves as a compelling case study illustrating the impact of perception. Scepticism regarding solar energy often prevails in regions where conventional energy sources, such as fossil fuels, have been historically predominant. Pakistan's dependence on imported fossil fuels has led to ongoing power

shortages, prompting the government to promote solar energy alternatives. Nonetheless, many elements of the populace remained suspicious owing to a lack of comprehension regarding advancements in solar technology and its capacity to address energy shortages (Millison et al., 2022). In response, the government initiated public awareness campaigns, highlighted successful solar installations, and informed locals about the advantages of solar energy. This initiative to alter perception fostered a more conducive environment for solar PV adoption.

Brazil elucidates the intricate relationship between perception and the use of solar energy. Numerous indigenous communities in the Amazon rainforest lack access to reliable electricity sources. Notwithstanding its potential to provide clean and sustainable energy, solar power is regarded as an impractical luxury. Non-profit organisations and governmental initiatives intervened to enhance awareness, demonstrating the feasibility of solar systems in these remote locations. They transformed solar energy from a theoretical notion into a viable remedy for energy poverty by dispelling misconceptions and showcasing concrete benefits. Nepal illustrates the transformative effect of public awareness campaigns. The country's challenging topography and various settlements rendered typical grid extension problematic. Nonetheless, insufficient understanding regarding the feasibility of solar technology resulted in resistance in specific regions. In response, the government and non-governmental organisations (NGOs) initiated educational programs illustrating how solar photovoltaic installations may provide dependable electricity in remote areas. Local communities adopted solar systems as awareness increased, leading to enhanced living conditions and economic opportunities (Mainali et al., 2014).

A prominent instance from Bangladesh illustrates the importance of public-private collaboration in transforming perceptions. The Grameen Shakti initiative pioneered solar household systems in rural areas. The project first faced suspicion due to the prevailing belief in centralised control; hence, it commenced with a comprehensive awareness campaign. Grameen Shakti facilitated discussions, challenged preconceptions, and provided practical demonstrations of the benefits of solar energy in partnership with local leaders and communities (Amin and Langendoen, 2012). This community engagement transformed perceptions, rendering solar energy a more attainable and valued resource.

The use of solar photovoltaic technology in underdeveloped countries is greatly affected by perception and awareness. Collaborations, educational initiatives, and public awareness campaigns can bridge knowledge gaps, dispel misconceptions, and transform perceptions of solar energy (Yousaf et al., 2021). Comprehending the significance of perception and awareness is essential for realising the vast potential of solar photovoltaic technology as countries transition to sustainable energy sources.

2.7 Solar Companies in Nigeria

There are numerous solar companies in Nigeria, however, for the sake of this article, we will be looking at the 20 best solar companies in Nigeria.

a. GVE Solar Company in Nigeria

Green Village Electricity (GVE) Projects Limited is the foremost and most innovative renewable energy solutions provider in West Africa, registered with the Corporate Affairs Commission of Nigeria (RC1071222).

Through the expertise and dedication of our board of Directors, management, employees, and various business associates, we have been able to position the company as the leader in Nigeria's renewable energy industry creating value for our numerous clients through world-class service delivery with a touch of unique local contexts.

Residential Solar Solution:

- Tailored installations for homeowners to harness solar power, reduce electricity bills, and transition away from traditional power sources.
- Customized designs using high-quality materials for optimal energy production and sustainability.
- Expert guidance and exceptional customer service to ensure a seamless transition to renewable energy for a brighter future.
- Commercial & Industrial Solution:
- Innovative solar solutions for businesses and industries, from small enterprises to large industrial operations.
- Custom-designed systems by solar experts to maximize energy efficiency and cost savings.
- Focus on quality, reliability, and customer satisfaction throughout the installation process to unlock the full potential of solar power for businesses.

Rural Electrification Solution:

- Eco-friendly solar-powered solutions to provide reliable electricity to underserved rural areas worldwide.
- Community-centric approach working closely with local leaders to design and implement customized solar solutions.
- Commitment to making clean energy accessible as a basic human right to power up rural communities and improve lives.
- Utility Management and Smart Metering Solution:
- End-to-end metering solution addressing utility management challenges in emerging markets.
- Smart metering infrastructure including AMR/AMI, smart vending system, metering data management system, and STS code management system.
- Empowering clients to make smart financial and environmental choices through solar energy investment.

Other Services:

- Consultancy Services: Expert advice and guidance on solar energy implementation and optimization.
- Solar Street Lighting: Solar-powered lighting solutions for streets and public areas.
- Renewable Energy Products Sales: Sales of a variety of renewable energy products.
- Energy Auditing: Assessments and recommendations for energy efficiency improvements.
- Training: Educational programs to empower individuals and organizations with knowledge about renewable energy technologies and practices.

b. Arthur Energy Technology Limited

Arthur Energy Tech Ltd is one of the few solar companies in Nigeria situated in Isolo. It is a solar company that has grown in prominence in the solar energy industry as a result of previous projects completed.

They also manage their services throughout Lagos. They are well-known for supplying and installing solar panels with unit standards for street lighting, agricultural lighting, boreholes, houses, schools, and businesses.

c. Energy Excel Systems and Solutions Limited

Energy Excel systems and solutions Ltd is an Abuja-based firm that sells, maintains, and installs deep cycle batteries, solar inverters, and UPS systems. In addition, the Abuja-based firm sells, installs, and maintains unit-specific solar goods such as solar traffic lights, solar street lamps, and solar submersible water pumps.

d. Enerplaz Renewable Energy

This is one of the few solar companies in Nigeria situated in Port Harcourt that specializes in solar products and services. They sell, distribute, and install solar inverters, batteries, and panels in homes, industries, businesses, and commercial settings.

e. Novel Power Systems

Novel Power Systems, located in the old city with brown rooftops, Ibadan, is a leading solar company in the ancient city and Oyo state. The Ibadan-based solar company sells, installs, and maintains solar inverters and batteries for homes, schools, factories, and commercial sectors.

f. Pamtronics Nigeria Limited

The Ikeja-based solar enterprise offers solar energy equipment sales, consults, and installations. They are largely focused on the installation of solar thermal systems and photovoltaics (PVs).

g. BETSAM Engineering Services

BETSAM engineering, located in the world-famous Ikeja Computer Village, is a solar company that handles the sales, installation, and maintenance of solar energy equipment in and around Lagos. The Ikeja-based solar company sells and installs solar panels, backup systems, and solar batteries for homes, businesses, ATMs, security lights, and data servers.

h. Rose Top Nigeria Limited

Rose top Nig. Ltd is a Lagos-based solar firm that specializes in solar energy product advice, sales, installations, and service for private and public clients. The Lagos-based company also installs, refines, and services petrol and diesel generators. Similarly, the company rents out generators to individuals. Rose Top is the 8th best among the various solar companies in Nigeria

i. Green Energy

Green Power, regarded as Nigeria's greatest solar enterprise, was created in 2006 and is focused on providing dependable, intelligent energy solutions using [renewable energy](#). The company's mission is to deliver energy conservation that is both environmentally beneficial and cost-effective. You may be assured of timely service delivery if you choose green electricity, owing to a highly dependable management and technical team. They have also built a good reputation over the years by providing services to individuals, telecommunications companies, private enterprises, schools, hotels, and hospitals, among others. They provide electrical installation services, as well as solar energy systems, solar thermal energy systems, backup inverter systems, and energy consulting.

j. Ecozar Technologies Inc

Ecozar Technologies is a company that offers excellent solar services at a cheap price. This is especially true when it comes to providing, installing, and maintaining high-quality solar systems and inverters. This company, launched in 2014, is a national leader. They are professionals in the installation of inverters and [solar power](#) systems in homes and businesses across the country. Ecozar Technologies also provides flexible service to customers in order to create strong customer connections. The routine follow-up examinations are also extremely nice. The company ensures that consumers receive the best solar installations possible.

k. Hians Energy Solutions Limited

Another prominent solar firm in Nigeria is Hians Energy, which specializes, among other things, in electrical wiring and the installation of renewable energy sources such as solar power. Because of their extremely competent technical team, you may be confident that you will receive the best. This is especially true when it comes to building a backup power inverter, getting solar power advice, and getting electrical services. You can talk to them about how many batteries or solar panels you'll need for your tiny house.

l. LEKS Environmental Limited

Leks is another well-known solar and renewable energy company in Nigeria. The company has made a name for itself in the energy industry. Since its inception in 2011, Leks Environmental Limited has become known for its sustainable energy and safety solutions. They also sell garbage and recycling equipment, medical emergency transportation services, and health and safety items. They also construct environmental and energy infrastructure.

m. Infinite Solar Solutions Nigeria Ltd

Infinite Solar Solutions Nigeria Limited is another reliable and fairly priced solar energy provider in Nigeria. They provide competent customer service personnel who help clients understand their needs. Importation, wholesale, and retail of solar products are other areas of specialization for Infinite Solar. They can put in solar street lights, hybrid and standalone inverters, solar lights, garden lights, solar refrigerators, solar panels, LED lights, and other things.

n. Solar Force Nigeria Plc

Solar Force Energy is Nigeria's most dependable renewable energy company. The company was created in 2007 and is dedicated to providing the general population with access to the most advanced solar technology available. SFN is a division of Solar Force Corporation in the United States. They offer genuine products such as Solar Streetlights, Mini Grids, Solar Boreholes, and others.

o. Wavetra Energy Limited

Wavetra Energy LTD is one of the best companies to work within the solar energy industry. Over the years, they have helped customers install a variety of solar energy technology, including solar panels, charge controllers, inverters, and deep-cycle batteries. In addition, Wavetra Energy LTD sells authentic LED bulbs, windmills, solar street lights, and related accessories.

p. Astrum Energy Solutions Ltd

Astrum Energy Solutions offers full-time solar renewable energy services. This solar company was founded in 2007. They install solar PV systems in homes, companies, and even entire towns. Customers that use this company rave about them. Astrum Energy Solutions Ltd has offices in Lagos, Port Harcourt, and Jos. You may count on them to provide timely and dependable renewable energy services. They also provide warranties for their solar services.

q. Rubitec Nigeria Limited

Rubitec Nigeria Ltd. is a famous solar energy company in Nigeria. The group provides backup choices for offices as well as different power sources for residences. This solar backup can power your appliances. Rubitec Nigeria also offers and installs farm agro-solar systems, biomass energy systems, and mini-grid systems. They provide services to both urban and rural communities in Nigeria.

r. Powertech Solar Energy Ltd

Powertech Solar Energy is well-known for supplying high-quality solar-powered products for your homes, companies, and industrial settings. This company was founded in 2010. It distributes solar things in quantity, large equipment, portable hybrid rooftop systems, solar energy equipment, and other items quickly and easily throughout Nigeria.

3. OPPORTUNITIES AND APPLICATIONS OF SOLAR ENERGY

The consistent availability of reliable power is a fundamental aspect of global advancement. However, this connection remains tenuous for numerous underdeveloped and rural regions in rising nations. Solar photovoltaic (PV) technology is emerging as a transformative force that offers a unique opportunity to enhance this fabric by illuminating the lives of individuals in areas previously unserved by modern energy sources. The significance of solar PV in addressing electrical poverty is exemplified by the dramatic case of Sub-Saharan Africa. This region continues to have millions of individuals lacking access to electricity, thereby constraining opportunities for progress. Rwanda exemplifies transformation. The Rwandan government collaborated with international partners to deploy decentralised solar systems, emphasising off-grid solar solutions (John et al., 2011; Adedeji et al., 2023). This collaborative initiative ignited educational empowerment while illuminating remote residences. The opportunity for pupils to study at night significantly enhanced their academic prospects and fostered a culture of learning. Similarly, solar photovoltaic energy has initiated a new era of possibility in central India, where millions reside in rural darkness. Dharnai village in Bihar exemplifies the transformative potential of solar microgrids on communities. The community had a prolonged absence of electricity for decades, hindering economic advancement and limiting access to healthcare services. The construction of a solar-powered microgrid revitalised the neighbourhood. With the illumination now pervasive, essential services became more accessible in residences, educational institutions, and healthcare facilities. This transition vividly demonstrated the connection between solar energy and the advancement of human potential (Mathai, 2022).

Bangladesh emphasises that solar energy may surmount challenges. The solar home system initiative became a crucial support for residents in the remote areas of the expansive nation. Despite the constraints of their geographical seclusion, off-grid families today possess access to clean and sustainable energy (Millison et al., 2022). This not only improved living conditions but also

enabled the villagers to utilise solar energy for productive activities such as operating small businesses and irrigating crops. Access to electricity served as a catalyst for comprehensive advancement within the development framework. The Mali-Folkecenter Nyetaa collaboration demonstrated the reciprocal advantages of solar energy and healthcare. Vaccines and pharmaceuticals requiring constant refrigeration can now be reliably kept by implementing solar-powered refrigeration units in healthcare institutions. This initiative had extensive repercussions that transcended the health facilities, as enhanced access to healthcare led to healthier communities, reduced disease burdens, and eventually improved quality of life. In rural and undeveloped areas, solar PV lamps represent a symbol of potential, providing energy access rather than merely functioning as light sources. Outside the confines of electrified homes, the ramifications of energy availability create a fabric of empowerment, resilience, and hope. Solar photovoltaic technology acts as a conduit to a more equitable and affluent future as developing countries strive to overcome the energy divide.

Moreover, the implementation of solar photovoltaic (PV) technology in renewable energy is not merely a transition to sustainable power; it also serves as a catalyst for economic transformation. The capacity of solar PV adoption to generate diverse employment opportunities along the whole value chain is one of its most attractive attributes. The significant impact of solar energy on job creation, encompassing manufacturing, installation, maintenance, and research, offers hope, especially for developing countries (Zhuo et al., 2021). An exemplary demonstration of the employment potential of this technology is evident in China, the global leader in solar PV installations. The country's industrial sector achieved unprecedented success due to its ambitious solar objectives. In response to the demand for solar panels, manufacturing hubs were formed, resulting in a significant increase in employment opportunities in production, quality control, and research and development. This substantially facilitated economic expansion and enabled millions to transcend poverty by generating stable employment opportunities.

Germany exemplifies the influence of solar PV adoption on employment. The expansion of the solar business was catalysed by the nation's unwavering dedication to the "Energiewende," or transition to renewable energy. Employment opportunities were generated in significant quantities, ranging from small-scale solar farms to extensive rooftop solar systems. With the expansion of the solar business, employment opportunities for engineers, technicians, sales personnel, and administrative staff flourished (Shaughnessy 2022). This surge in employment expansion permeated several areas of the economy, fostering a sense of sustainable development and collective empowerment. Kenya exemplifies a noteworthy case from the African continent. Local solar enterprises specialising in both off-grid and grid-connected systems were formed due to the Kenyan government's initiative to increase solar energy utilisation. Consequently, roles spanning from sales and marketing to technicians specialising in solar systems were established. Both urban and rural areas capitalised on these employment opportunities, contributing to the nation's economic advancement and poverty alleviation initiatives (Ditlev-Simonsen, 2022).

The solar home system initiative in Bangladesh promoted self-employment and entrepreneurship. Solar household systems were installed and maintained by locally trained technicians, creating a network of professionals that enhanced electricity access and stimulated local economies. The expansion of the solar sector cultivated an ecosystem of suppliers, instructors, and technicians, illustrating how solar energy may promote a broad labour market. The use of solar PV technology

acts as a catalyst for employment expansion throughout the value chain. Solar photovoltaic technology presents significant opportunities for substantial employment and aids in achieving sustainable development objectives as developing countries seek to enhance economic growth and alleviate poverty (Thilanka et al., 2021).

Solar photovoltaic (PV) technology emerges as a beacon of hope in the face of pressing global environmental concerns, serving not only as an energy source but also as a pathway to environmental restoration and sustainable development. The environmental benefits of solar photovoltaic technology significantly impact climate change mitigation and the attainment of sustainable development objectives, as it can substitute fossil fuels and diminish carbon emissions. Germany is a resolute advocate for the environmental benefits of solar photovoltaic technology. Substantial decreases in greenhouse gas emissions were attained due to the nation's considerable investment in renewable energy, particularly solar power. Germany achieved significant advancements in reducing its reliance on fossil fuels when the proliferation of solar panels occurred. This alteration not only facilitated a more sustainable energy composition but also positioned the nation as a global frontrunner in the utilisation of renewable energy sources (Shaughnessy, 2022).

In Costa Rica, solar energy generation and environmental conservation coexist together. The country's commitment to sustainability allowed it to generate 100% renewable energy for prolonged durations. Costa Rica diminished its reliance on foreign fossil fuels while concurrently lowering carbon emissions by using its abundant solar energy. This remarkable accomplishment demonstrated the capacity of solar photovoltaics to foster sustainable growth while conserving natural resources. China, often associated with rapid industrialisation and environmental challenges, shows the transformative potential of solar photovoltaic technology. The rise in solar installations resulted from the nation's efforts to transition to more sustainable energy sources. This significant transformation substantially aided worldwide initiatives to alleviate climate change while enhancing air quality and decreasing reliance on coal (Millison et al., 2022). The pivotal importance of solar photovoltaic technology in shaping a sustainable future is evidenced by China's transition from the foremost emitter of greenhouse gases to a frontrunner in renewable energy (Adelakun and Olanipekun, 2019).

The Noor Ouarzazate Solar Complex in Morocco exemplifies the potential of solar energy for environmental conservation. The complex, among the largest solar power facilities globally, reduces Morocco's dependence on fossil fuels and thereby diminishes carbon emissions. This modification aligns with the nation's commitment to reduce its carbon footprint and bolster global initiatives to address climate change (Mohamed and Touhami, 2020). The adoption of solar PV technology exemplifies human ingenuity in enhancing our relationship with the environment, beyond mere electricity generation. Solar photovoltaic technology (PV) represents a promising solution as the world grapples with the challenges of climate change and sustainable development, offering a viable method to reconcile expansion with environmental stewardship.

Moreover, solar photovoltaic (PV) technology is crucial in the integration of renewable energy sources, as it addresses pressing energy challenges while simultaneously providing a platform for innovation. The challenges faced in the use of solar energy in poor countries serve as a catalyst for innovative solutions. The challenges of solar adoption drive technological innovation, shaping the

path towards cleaner, more sustainable energy futures (Dirk and Sven, 2021). These breakthroughs encompass pioneering technology, creative financial frameworks, and tailored commercial solutions.

Bangladesh exemplifies a remarkable case study of technical innovation arising from adversity. The country's highly populated metropolitan centres encountered significant challenges in the development of solar power due to insufficient available space. In response, enterprises developed innovative solutions such as rooftop solar systems and solar-powered charging stations (Huang, 2021). These specialised, advanced approaches, tailored for urban environments, not only improved solar implementation but also facilitated increased access to electricity. Kenya exemplifies how technology can address challenges associated with conventional infrastructure, particularly in areas where isolated populations often lack access to energy. The advent of mobile payment networks facilitated innovative financing models for solar energy. Pay-as-you-go solutions enabled families to finance solar systems incrementally, despite the absence of upfront capital. The convergence of technology and capital changed energy availability, showcasing the transformative potential of innovation (Marina et al., 2020).

Technology-driven solutions have been essential in addressing challenges in India, a country distinguished by its diverse energy landscape. The advancement of solar-powered microgrids has proven essential in providing electricity to remote villages and underserved regions. When integrated with smart grid technology, these decentralised systems offer specialised solutions that transcend the limitations of traditional infrastructure development and ensure reliable energy availability (Shaughnessy 2022; Acosta et al., 2016). Tanzania exemplifies how the desire for energy solutions may stimulate innovation. The deficiency of access to modern energy services in remote areas necessitated novel solutions. Companies developed portable solar-powered lanterns and home systems, transforming illumination and communication in off-grid communities. These technological breakthroughs facilitated innovative methods for communities to harness solar energy, whilst serving as a crucial source of electrical access. The challenges of deploying solar PV in impoverished nations are not insurmountable barriers; instead, they act as catalysts for technological progress. Technological innovation serves as a beacon, illuminating a path towards a more sustainable and equitable energy future as the world confronts the obstacles of transitioning to cleaner energy sources.

In conclusion, developing countries are poised for a significant opportunity in the transition to sustainable energy. International assistance, encompassing loans, grants, technical support, and collaborative partnerships, serves as a beacon of optimism, igniting the impetus necessary to promote the use of solar photovoltaic (PV) technology. The essential function of international collaboration in advancing solar energy deployment, as evidenced by case studies that illustrate the capacity for cooperative initiatives to accelerate development and foster a cleaner, more equitable energy landscape (El-Hagggar and Samaha, 2019).

International aid has catalysed the use of solar energy in Sub-Saharan Africa, creating a poignant context for this advancement. A prime illustration is the International Finance Corporation's (IFC) Scaling Solar initiative. This program promotes public-private partnerships to optimise project development processes and attract private investment in countries such as Zambia and Senegal. International groups establish the foundation for solar initiatives that enhance energy availability

and stimulate economic development by providing technical expertise, aiding regulatory frameworks, and mobilising financial resources. Haiti, a nation grappling with energy poverty, exemplifies the necessity of international collaboration for sustainable development. The Solar Market Gardens initiative was initiated by the Solar Electric Light Fund (SELF) in partnership with local organisations and international financiers. This initiative enhanced agricultural output and elevated living standards through the implementation of solar-powered water pumps, drip irrigation systems, and educational programs. These collaborative endeavours demonstrate that global aid can extend beyond energy accessibility and catalyse additional advancements.

The International Solar Alliance (ISA) exemplifies the collaboration between developed and developing countries. The ISA unites countries to address challenges related to solar energy development, aiming to mobilise over one trillion dollars in investments for solar projects by 2030. This initiative was spearheaded by France and India, demonstrating how global cooperation can catalyse the growth of the solar sector. The Green Climate Fund (GCF) exemplifies the commitment of multinational groups to advancing solar energy utilisation. The GCF provides financial and technical assistance for climate mitigation and adaptation programs in impoverished countries. The GCF endorses solar initiatives such as Uganda's Rural Electrification Programme, promoting energy accessibility and aligning with broader sustainable development objectives. The objectives of developing nations are linked to the expertise and resources of the global community through foreign assistance, which acts as a conduit. International collaborations illuminate the path, fostering resilience, strengthening communities, and establishing a shared direction towards a more sustainable and inclusive world as developing nations navigate the arduous journey towards cleaner energy futures.

4. RECOMMENDATIONS

As solar PV adoption expands in developing nations, numerous recommendations arise as guiding principles for a more effective and equitable transition:

- a) Governments ought to develop stable and supportive regulatory frameworks that promote private investment, innovation, and local entrepreneurship. Well-defined policy frameworks, incentives, and efficient approval processes can substantially expedite the deployment of solar photovoltaic technology.
- b) Capacity Building: To address the deficiency in technical abilities, it is imperative to finance training programs, educational initiatives, and skill development. Sustained success relies on empowering local communities with the knowledge and skills necessary for solar PV installation, maintenance, and management.
- c) Innovative Financing: For resource-constrained areas, solar PV systems may be economically viable through microloans, pay-as-you-go strategies, and public-private collaborations. Financial aid could be further enhanced through collaboration with international financial institutions and organisations.
- d) Awareness and Education: Educational programs and public awareness campaigns elucidate misconceptions, enhance knowledge, and cultivate a culture of acceptance for solar energy. The broader adoption of solar technology may be promoted by presenting tangible examples of its benefits.

- e) The significance of foreign aid cannot be overstated in joint projects. Collaborations with international groups and partnerships between developed and developing nations can furnish resources, expertise, and impetus for solar energy initiatives.

In conclusion, the trajectory towards the adoption of solar photovoltaic technology in impoverished nations is fraught with possibility, promise, and a necessity for concerted efforts. The challenges faced are not impediments to overcome, but rather catalysts for innovation and progress. We can forge a path to a more sustainable, equitable, and robust future for everybody by harnessing the promise of solar energy. Collaborative efforts across governments, organisations, communities, and individuals contribute to a narrative of transformation, resilience, and hope that transcends national boundaries and shapes the trajectory of the world.

5. CONCLUSION

The path to solar photovoltaic (PV) adoption in developing countries is a challenging aspect of global development, characterised by difficulties, achievements, and boundless potential. Upon examining the various aspects of this project, it is evident that, despite the obstacles present, opportunities and potential remain, facilitating a future with cleaner, more sustainable energy sources.

The challenges encountered in the deployment of solar photovoltaic technology, encompassing budgetary limitations, infrastructure deficiencies, and governmental obstacles, are not insurmountable. They represent the convergence of creativity, determination, and collaboration, resulting in the formation of new pathways. The financial complications that formerly hindered development are being increasingly addressed through novel financing arrangements, incentives, and cooperative investments. Infrastructure limitations have catalysed the advancement of hybrid technologies, decentralised networks, and intelligent grids, fundamentally transforming energy acquisition and utilisation. Transparent frameworks and progressive rules that acknowledge the transformative potential of solar energy are swiftly supplanting regulatory impediments.

Access to energy, job creation, environmental conservation, technological progress, and international collaboration are all promising prospects in the horizon. The unparalleled capacity of solar PV to illuminate dark areas, stimulate local economies, diminish carbon emissions, foster innovation, and establish international partnerships is noteworthy. These elements collectively present a compelling case for action and investment from individuals, governments, and organisations who see the importance of this juncture in shaping the sustainable future of our world.

Acknowledgement

The authors wish to acknowledge the funds provided for this research and publication by TETFund Centre of Excellence for Renewable Energy, Kaduna Polytechnic, Kaduna, Nigeria. The funds were provided by the Tertiary Education Trust Fund (TETFUND), Nigeria, under the TETFUND Special Intervention for Establishment of Centre of Excellence (TETF/ES/DS&D/KADPOLY/COE /2021/VOL11).

Conflicts of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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