International Journal of Physical Sciences Research, 7 (1), 36-57, 2023
Print ISSN 2515-0391 (Print)
Online ISSN 2515-0405 (Online)
Website: https://www.eajournals.org/
Publication of the European Centre for Research Training and Development-UK

Adoption of Solar PV in Developing Countries: Challenges and Opportunity

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doi: https://doi.org/10.37745/10.37745/ijpsr.17/vol7n13657 Published September 11 2023

Citation: Ibegbulam, M.C., Adeyemi, O. O., Fogbonjaiye, O.C. (2023) Adoption of Solar PV in Developing Countries: Challenges and Opportunity, *International Journal of Physical Sciences Research*, 7 (1), 36-57

ABSTRACT: *The increasing global demand for energy and sustainable development have led to the adoption of solar photovoltaic (PV) technology as a promising solution. Developing countries, with diverse challenges and aspirations, are at a pivotal juncture where solar PV adoption can catalyze transformative change. This study reviews the adoption of solar photovoltaics in developing countries with emphasis on challenges and opportunities. This study discusses the State of Solar PV, Challenges of Solar PV in Developing Countries, and Opportunities and areas of applications. Developing counties are on the verge of a dramatic opportunity in the transition to sustainable energy. International help, in the form of loans, grants, technical support, and cooperative alliances, is a ray of hope, sparking the momentum required to spur the adoption of solar photovoltaic (PV) technology. The crucial role that international collaboration plays in promoting the deployment of solar energy, drawing conclusions from case studies that demonstrate the potential for cooperative efforts to expedite development and create a cleaner, more equitable energy environment. Tanzania serves as an example of how demand for energy solutions may encourage creativity. Haiti, a country that struggles with energy poverty, serves as an example of how international cooperation may be vital to sustainable development. The Solar Market Gardens project was started by the Solar Electric Light Fund (SELF), in collaboration with regional groups and foreign funders. This project increased agricultural production in Haiti.*

KEYWORDS: solar photovoltaic, developing countries, renewable energy, energy access, environmental benefits, technological innovation, limitations.

INTRODUCTION

Exploration of renewable energy sources has become an inescapable quest in an era characterized by a relentless surge in global energy consumption and an urgent requirement for sustainable development (Kenu, 2020). Solar photovoltaic (PV) technology has arisen as a beacon of hope among the pantheon of alternatives, promising to revolutionize the energy landscape with its inherent virtues of plenty and environmental benignity (Nimay et al., 2021).

This study digs into the enthralling world of solar PV adoption, with a special emphasis on the benefits and challenges it brings for developing nations (Carvalho, 2021).

The undeniable rise in global energy consumption casts a looming shadow over the present and future (Pratish, 2021; Dania, 2020). This voracious need for energy, fuelled mostly by finite fossil fuel supplies, promotes economic expansion while also emphasizing the critical importance of diversifying the energy mix. Concurrently, the imperatives of sustainable development, resonating along international corridors, call for a shift away from the entrenched carbon-intensive trajectory (Haris and Sarwar, 2013).

Figure 1 shows the two types of energy source which is renewable and non-renewable energy. The world is moving away from non-renewable energy sources like petroleum (Ukoba et al., 2011) because they contribute greenhouse gases which continue to warm the planet. Renewable energy emerges as a tangible lifeline at this vital juncture, with solar PV taking a commanding position among them. Other types of renewable energy include wind (Ukoba et al., 2023), hydro (Adhikari et al., 2023), biomass (Imoisili et al., 2014).

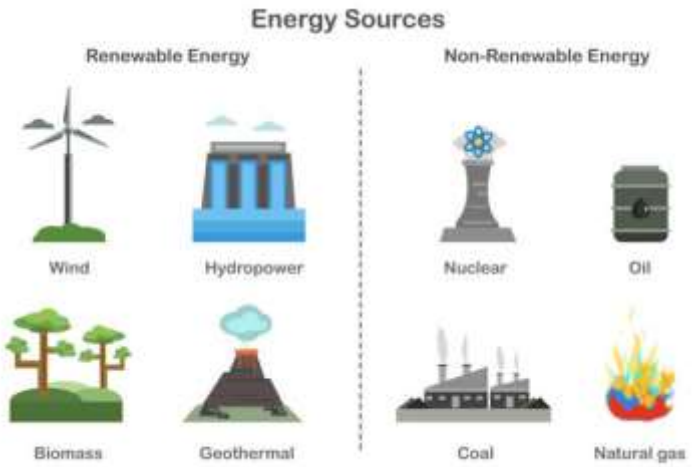

Figure 1. Energy sources

Solar Photovoltaic Technology

Photovoltaics (often shortened as PV) gets its name from the process of converting light (photons) to electricity (voltage), which is called the photovoltaic effect. Solar PV technology, which is based on the fundamental premise of transforming sunlight directly into power, has an undeniable charm. There are three main types of solar PV systems: grid-tied, hybrid and off-grid. Each type of solar panel system has its advantages and disadvantages, and it really comes down to what the customer wants to gain from their solar panel installation. There are thin film, monocrystalline and polycrystalline solar panels as shown in figure 2.

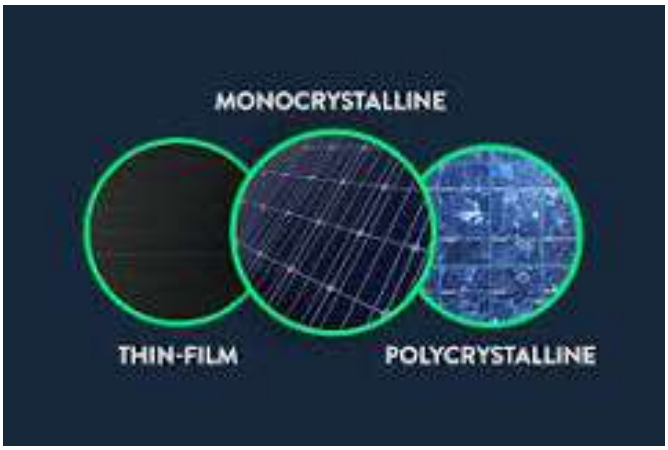

Figure 2: Types of solar PV

Solar photovoltaic systems generally consist of six individual components: the solar PV array, a charge controller, a battery bank, an inverter, a utility meter, and an electric grid. The correct installation of all of these components determines how efficient the solar system solution would be. Solar energy can be classified into two categories depending upon the mode of conversion and type of energy it is converted into. Passive solar energy and active solar energy belong to the mode of conversion and solar thermal energy, photovoltaic solar power and concentrating solar power.

This technique resonates with promise across the sun-drenched expanse of emerging countries (Abdelrazik et al., 2022), ushering in a new age of energy generation. The natural abundance of solar radiation in these areas heralds the possibility of energy democratization, freeing marginalized groups from the constraints of energy poverty (Shafqat et al., 2018). Remote villages and metropolitan slums alike may bask in the splendour of electrification, sparking the flames of progress and improving human well-being with the sun as an egalitarian friend.

Solar PV's environmental impact cannot be over-emphasized. Its functioning is surprisingly inconspicuous, producing zero emissions while providing relief to the ailing earth. As developing countries strive to avoid the negative growth paths taken by their industrialized counterparts, solar PV becomes a vital tool (Nogin et al., 2023). This technology transforms into an embodiment of responsible development, guaranteeing that the pursuit of wealth does not have a negative impact on the delicate ecosystems that sustain life (Wyllie et al., 2018).

Developing nations are at the epicentre of transition in the tapestry of the potential created by solar PV. Countries such as South Africa have started deploying solar PV both in rural and urban centres for electricity generation as shown in Figure 3.

Figure 3. A solar panel seen in a South African residence

The convergence of three critical factors—energy poverty, carbon emissions, and economic advancement—makes solar PV adoption a very promising endeavour. The pages of the chronicles of energy poverty are dominated by themes of doom—communities suffocating in the dark, devoid of basic comforts and opportunity (Victoria et al., 2021). However, amid this melancholy, solar PV shines as a light of hope. Its decentralized character allows for the formation of microgrids that cross perilous terrains, lighting lives and enabling the development cascade (Islami et al., 2021; Yoldaş et al., 2017).

The spectre of carbon emissions, which haunts the global climate change debate, finds a foil in solar PV. As these nations walk the fine line between development and environmental stewardship, solar PV beckons as a solution, providing a way to reduce carbon footprints without compromising growth. Furthermore, the appeal of economic expansion, which is the underpinning of developing countries' goals, has found an unlikely companion in solar PV. The potential for employment creation along the value chain, from production to installation and maintenance, redraws the boundaries of prosperity (Bunda et al., 2023).

Additionally, substantial solar PV deployment is accompanied by a phalanx of difficulties that need sophisticated answers. As underdeveloped nations struggle with limited financial resources, the high upfront costs of solar systems appear to be a significant obstacle (Varun et al., 2016). Furthermore, the inadequate grid infrastructure, plagued by fragility and instability, requires extensive upgrades to accommodate the onslaught of solar energy. Another issue is the tangle of rules and procedures, which necessitates concerted efforts to build a climate favourable to solar investment. Furthermore, a lack of technical skills creates a tragic situation,

emphasizing the need for capacity-building to successfully utilise the sun's potential (Wim and Smeets, Anse, 2022).

However, the crucible of solar PV development in developing nations is an alluring region where promise and obstacles mingle in a delicate dance. The backdrop for this story is a symphony of growing global energy consumption, sustainable development imperatives, and the revolutionary promise of solar PV. This paper will unravel the mosaic of problems that throw their shadows on this promise, mixed with the iridescent opportunities that beckon as guides towards a more sustainable future.

In the early stages of solar PV adoption, financial hurdles impede widespread implementation. Limited resources, infrastructure constraints, and policy and regulatory barriers add complexity to solar PV deployment. Examples from Sub-Saharan Africa, the Caribbean, and South Asia demonstrate hybrid solutions, intelligent grid systems, and microgrids that overcome infrastructural limits.

Policy and regulatory barriers further complicate solar PV deployment. Private investments can be stifled by inconsistent legislation, bureaucratic difficulties, and a lack of supportive frameworks. However, clear and stable regulatory settings are crucial for solar energy growth. Limited technical experience poses a problem to the efficient design, installation, and maintenance of solar PV systems.

The trajectory of solar PV adoption is heavily influenced by perception and awareness. Misconceptions about the dependability, price, and benefits of solar energy can stymie growth. Solar PV offers increased energy access, job development, environmental advantages, technology innovation, and international collaboration. It provides reliable electricity to remote and disadvantaged areas through decentralized solutions, off-grid systems, and new finance mechanisms, supporting education, healthcare, and overall well-being.

Technological innovation is a cornerstone, demonstrating how the limitations of solar adoption spur inventive solutions. Localized technologies, smart grids, and microgrids are reshaping energy landscapes, particularly in areas with diversified energy needs. International help in the form of grants, loans, technical assistance, and collaborations provides a lifeline for developing countries attempting to adopt solar energy.

The journey towards solar PV adoption in developing countries is a kaleidoscope of problems, possibilities, and aspirations. This study navigates a maze of financial restrictions, infrastructure constraints, policy roadblocks, technical expertise gaps, and perception issues, demonstrating solar energy's revolutionary potential through energy access, job development, environmental stewardship, technological innovation, and international assistance. Adoption of solar PV emerges as a lighthouse, illuminating the path towards resilient, empowered, and equitable societies in the developing world.

State of Solar PV

The end product and hope of green economy enthusiasts is that solar PV will power almost the world as shown in Figure 4.

Figure 4. Adoption of solar PV for global electricity generation

Although, Solar photovoltaic (PV) technology has seen a tremendous transformation, crossing borders and reshaping energy landscapes all over the world. As the world grapples with the imperatives of sustainable development and climate action, the condition of solar PV emerges as a beacon of hope, representing not only the progress made but also the possibility for much larger future achievements. Solar PV use has shifted dramatically over the last two decades, from a marginal technology to a worldwide powerhouse. Solar panels on roofs, commercial buildings, and utility-scale projects have been deployed first in developed nations. Countries such as Germany, China, the United States, and Japan have not only shown the practicality of solar energy but have also laid the groundwork for poor countries to follow suit (Usha and Douglas, 2011).

The condition of solar PV, on the other hand, is not limited to developed economies. Developing countries have jumped into the race with zeal, due to plentiful sunshine and rising energy demands (Jacob, 2016). Solar PV expansion in these countries is fuelled by a convergence of variables, including energy access requirements, economic growth ambitions, and environmental stewardship pledges. These nations are progressively adopting solar energy in order to close energy gaps, create employment, decrease carbon emissions, and stimulate technical innovation. One of the most intriguing characteristics of solar PV today is its ability to promote equitable development. Solar microgrids, off-grid systems, and new finance methods are illuminating isolated villages, empowering people, and improving education, healthcare, and general quality of life. The combination of solar energy and technology is giving birth to solutions that go beyond energy access, promoting economic growth while fostering environmental sustainability (Hashwini et al., 2021).

Going forward, the condition of solar PV looks to be on the verge of a dramatic shift. Solar panels' efficiency and price continue to improve as technology advances, making them more accessible. Energy storage options, together with improvements in battery technology, are tackling the intermittency issue, guaranteeing that solar energy stays dependable even after sunset (Mehdi et al., 2023). Smart grids, Internet of Things (IoT) connectivity, and decentralised energy systems are all pointing to a future in which solar energy would not only power houses but potentially entire cities. The worldwide resolve to address climate change is catapulting solar PV into the spotlight. International alliances, such as the International Solar Alliance, demonstrate the global determination to promote solar energy adoption. Financing methods and legislative frameworks are being refined to promote solar projects in developing nations, indicating a growing appreciation for solar energy's ability to drive global sustainable development.

The situation of solar PV is at the crossroads of progress and promise. Developed countries have created the groundwork while developing nations see solar energy as a catalyst for change. The contemporary landscape is defined by technological advancements, inclusive development, and global alliances, pointing to a future in which solar PV emerges as a transformational force, guiding us towards a more sustainable, equitable, and empowered society.

Challenges of Solar PV in developing countries

The move to solar photovoltaic (PV) technology in developing countries is certainly fraught with difficulties, with financial constraints being one of the most daunting. The high initial cost of installing solar PV systems is a key hurdle to the widespread adoption of this potential renewable energy source. Developing nations frequently have budgetary constraints, directing their emphasis to critical sectors such as healthcare, education, and infrastructure. As a result, providing large expenditures for solar PV installations becomes a difficult task.

The investment necessary for solar panels, inverters, and energy storage devices, although promising long-term benefits, imposes a significant upfront cost on many individuals and governments (Moner-Girona et al., 2021). India is a dramatic example of the financial difficulties associated with solar PV adoption. Despite its lofty solar ambitions and vast solar potential, the country has faced challenges owing to budgetary restrictions. The Indian solar business relied significantly on outside investment in its early phases since local financial institutions were hesitant to engage in untested technology. The formation of schemes such as the International Solar Alliance intended to pool resources and use economies of scale to lower costs, emphasising the collaborative approach required to overcome financial obstacles (Oguntuase, 2022). Bangladesh is yet another striking example. The country attempted to increase power availability to distant regions through its strong solar home system programme. Despite its success, the initial outlay remained a barrier for many low-income households.

To address this, novel financing options such as pay-as-you-go systems and microloans were established, allowing families to receive solar energy without incurring the whole financial

burden upfront. A similar story is playing out in Kenya. The high cost of solar systems has discouraged many from adopting the technology. In response, mobile payment networks were used to develop pay-as-you-go models, allowing homeowners to pay for their solar systems progressively over time. This innovative strategy avoided prohibitive upfront costs and promoted more solar PV deployment, hence contributing to improved energy access and economic growth (Adwek et al., 2020).

The initial high cost of solar PV installation in developing nations is a significant barrier to wider adoption. The experiences of these developing countries, demonstrate that creative finance methods, collaborative efforts, and focused interventions may effectively overcome these financial constraints (Mehdi et al., 2023). As these countries chart their course towards more sustainable energy futures, ingenuity, resourcefulness, and strategic alliances emerge as critical allies in the effort to realise the revolutionary potential of solar PV technology.

On the road towards sustainable energy transformation, another fundamental barrier hindering the smooth integration of solar photovoltaic (PV) systems in poor countries is a lack of infrastructure. The embryonic nature of grid infrastructure, along with inconsistent power supply and insufficient storage capacity, casts doubt on solar arrays' viability. Sub-Saharan Africa is a prime example of the severe infrastructural difficulties that frequently stymie solar PV deployment. The region struggles with a lack of established grid networks, making integrating intermittent solar power sources a daunting undertaking. Nigeria, for example, is confronted with the reality of inconsistent electrical supply as a result of antiquated and inadequate grid infrastructure. This shortcoming impedes the smooth integration of surplus solar energy into the grid, reducing the benefits of solar installations and dampening attempts to electrify rural regions (Nwaigwe et al., 2019). Haiti, located in the Caribbean, has a similar story. The energy landscape in the nation is characterised by brittle and inefficient grid networks. While solar PV projects seem promising, the absence of modern infrastructure makes it difficult to properly feed extra energy into the grid (Keston, 2020).

This constraint highlights the complex interplay between solar adoption and the urgent need for significant grid upgrades. Despite its successful solar home system programme, Bangladesh is not immune to infrastructural challenges. The low storage capacity of batteries becomes a stumbling problem in rural regions where solar household systems are proliferating. As a result, solar energy is underutilised, and potential productive uses are hampered. To solve this difficulty, creative techniques such as installing energy-efficient appliances and local microgrids have arisen, allowing communities to maximise the benefits of solar electricity while working within the constraints of limited infrastructure. The absence of infrastructure in developing nations makes efficient integration of solar PV systems difficult and they attempt to capture the power of the sun, they must manage the complex interplay between solar technology and the infrastructure that depends on its performance.

Additionally, the adoption of solar photovoltaic (PV) technology in developing countries is hampered by governmental and regulatory obstacles. The complex network of contradictory rules, cumbersome bureaucratic procedures, and a lack of supportive policy frameworks might

throw doubt on solar energy's potential. Nigeria provides a powerful case study, demonstrating the negative consequences of regulatory uncertainty. The nation's energy industry is managed by a maze of regulations that provide opportunities for interpretation and generate uncertainty. As a result, potential solar project investors are frequently ensnared in a web of contradictory rules and uncertain administrative processes (Haris and Sarwar, 2013). Lack of legislative clarity stifles private investment and slows the expansion of solar PV, impeding Nigeria's progress towards a sustainable energy future.

Chile, on the other hand, shows the transformational impact of favourable policy settings. The country's Renewable Portfolio Standard (RPS) requires a set amount of power to come from renewable sources, such as solar PV. This clear and consistent strategy not only drew major private investment but also catapulted Chile to the forefront of solar energy development (Chiara and Francesca, 2021). The adoption of open rules and forward-thinking policies produced an atmosphere that encouraged innovation, stimulated investment, and accelerated solar PV growth. Another convincing example is the United Arab Emirates (UAE). In a region historically reliant on fossil fuels, the UAE took unprecedented steps by enacting rigorous regulations that supported the deployment of renewable energy, particularly solar PV. The UAE established a reliable revenue stream for investors by introducing feed-in tariffs and power purchase agreements (PPAs) with set pricing for solar energy, catalysing fast expansion in the solar sector. This proactive policy posture altered the country's energy sector and exemplifies the transformational power of supporting rules (Kılıç and Kekezoğlu, 2022). Even within the same country, different regulatory environments might have disparate results. Gujarat, India, has emerged as a solar powerhouse, owing in part to aggressive legislative actions. Gujarat drew considerable private investment and became a forerunner in solar energy generation by giving attractive incentives, expedited permits, and a suitable atmosphere for solar project construction. In contrast to other Indian states with less favourable regulatory regimes, this highlights the critical significance of policy in driving solar PV development trajectories.

The maze of governmental and regulatory obstacles poses a substantial barrier to the broad deployment of solar PV technology in developing nations. A stable, transparent, and supportive legislative framework may be the driving force behind solar PV adoption, attracting private investment, and paving the road for sustainable energy transitions. As these countries strike a careful balance between development imperatives and regulatory clarity, they find themselves at a fork in the road towards a cleaner, more sustainable energy future.

Furthermore, a major impediment to the widespread adoption of solar photovoltaic (PV) technology in developing nations is a lack of technical skills. The complex art of planning, installing, and maintaining solar PV systems necessitates the use of qualified specialists and technicians. Unfortunately, a lack of such skills is a major impediment to the successful implementation of solar projects. Sub-Saharan Africa exemplifies the consequences of low technical knowledge. While the potential for solar energy is enormous, the region's capacity to efficiently exploit this resource is hampered by a lack of educated personnel. Tanzania, for example, is suffering from a scarcity of experienced solar specialists. As a result, system installs

are suboptimal, system life spans are lowered, and maintenance practises are poor. This information gap impedes not just energy availability but also the long-term profitability of solar PV projects (Jacob, 2016).

Bangladesh provides a different perspective on this issue. The dearth of skilled workers was a challenge as the country pursued rural electrification through solar household systems. Due to a dearth of specialists capable of handling technical difficulties and providing maintenance, installed systems were underutilized and the benefits of solar energy were not fully realized. The need of investing in capacity building became clear as the demand for competent human resources became obvious (Amit et al., 2022). The International Solar Energy Society (ISES) has identified a common thread in many developing countries: a dearth of targeted training programmes and educational activities to create solar competence. The lack of thorough training not only limits solar worker development but also perpetuates a cycle of undeveloped solar installations.

In contrast, Morocco is a shining example of success in overcoming the technical competence gap. As it began on big solar projects like the Noor Ouarzazate Solar Complex, the country recognised the importance of developing a competent solar workforce. Morocco created training programmes and knowledge-sharing initiatives in collaboration with foreign partners and organisations. These initiatives enabled Moroccan technicians and engineers, allowing large-scale solar projects to be completed successfully and positioning Morocco as a pioneer in solar energy development.

The lack of technical skills is a substantial barrier to solar PV development in developing countries. As countries traverse the difficulties of solar technology adoption, investing in qualified people serves as a lighthouse, blazing a way towards sustainable energy futures and assuring the long-term viability of solar PV projects.

Finally, an invisible yet powerful impediment to renewable energy adoption, particularly in developing nations, is perception and awareness. When compared to traditional energy sources, the viability of solar energy as an alternative may be hampered by a lack of awareness about its benefits or misunderstandings about its dependability and price (Bernadette and Michael 2016). Pakistan is a striking case study that demonstrates the influence of perception. Scepticism about solar energy can dominate in areas where traditional energy sources such as fossil fuels have historically been the norm. Pakistan's reliance on imported fossil fuels has resulted in persistent power outages, pushing the government to encourage solar energy options. However, some segments of the population remained sceptical due to a lack of understanding about advances in solar technology and its ability to solve energy shortages (Millison et al., 2022). In response, the government launched public awareness programmes, showcased successful solar installations, and educated residents about the benefits of solar energy. This effort to change perception contributed to a more favourable climate for solar PV uptake.

Similarly, Brazil sheds light on the complex link that exists between perception and solar energy uptake. Many indigenous settlements in the Amazon jungle lack access to dependable energy. Despite its promise to offer clean and sustainable power, solar energy has been perceived as an unattainable luxury. Non-profits and government efforts stepped in to promote awareness, proving the viability of solar systems in these isolated places. They changed solar energy from an abstract concept to a practical solution to energy poverty by debunking myths and demonstrating tangible advantages. Nepal exemplifies the transforming impact of public awareness initiatives. Because of the country's rugged geography and numerous settlements, traditional grid extension was difficult. However, a lack of awareness about the practicality of solar technology led to opposition in certain areas. To combat this, the government and non-governmental organisations (NGOs) started education programmes demonstrating how solar PV installations could deliver reliable electricity in even the most distant regions. Local communities embraced solar systems as awareness grew, resulting in improved living circumstances and economic prospects (Mainali et al., 2014).

One notable example from Bangladesh demonstrates the significance of public-private cooperation in altering views. The Grameen Shakti project pioneered rural solar household systems. The project was first received with scepticism owing to the prevalent notion of centralised power; therefore, it began with a complete awareness campaign. Grameen Shakti encouraged talks, refuted stereotypes, and gave practical demonstrations of the advantages of solar energy in collaboration with local leaders and communities (Amin and Langendoen, 2012). This community involvement shifted views, making solar energy a more accessible and valuable resource.

The adoption of solar photovoltaic technology in developing nations is significantly influenced by perception and awareness. Partnerships, education programmes, and public awareness efforts may close knowledge gaps, debunk myths, and change the way people think about solar energy (Yousaf et al., 2021). The understanding of the role of perception and awareness becomes a crucial component in unlocking the immense potential of solar PV as nations manage the shift to greener energy sources.

Opportunities and areas of applications of Solar

The underlying thread of dependable power availability runs across the vast tapestry of global progress. But this thread is still frayed for many undeveloped and rural areas in emerging nations. Solar photovoltaic (PV) technology is emerging as a revolutionary force that presents a rare chance to mend this fabric by bringing light to people's lives in regions that had not previously been served by contemporary energy sources. Understanding the importance of solar PV in solving electricity poverty can be better understood by looking at Sub-Saharan Africa as a dramatic example. This region still has millions of people without access to power, which limits prospects for advancement. An example of transformation is Rwanda. The Rwandan government worked with foreign partners to implement decentralised solar systems with a strategic focus on off-grid solar solutions (John et al., 2011; Adedeji et al., 2023). This coordinated effort stoked the flames of educational empowerment in addition to providing light

to isolated houses. The option for students to study after dark greatly improved their academic chances and promoted a culture of learning. In the same vein, Solar photovoltaic energy has ushered in a new era of opportunity in the centre of India, where millions of people live in rural darkness. Bihar's Dharnai village is a prime example of how solar microgrids have the power to alter communities. The town lived without power for decades, which prevented economic development and restricted access to healthcare. The installation of a solar-powered microgrid, however, gave the community new life. Now that everything was drenched in light, vital services were more readily available in homes, schools, and healthcare facilities. This changeover powerfully illustrated the link between solar energy and the development of human potential (Mathai, 2022).

Bangladesh highlights the idea that solar energy can overcome obstacles. The solar home system programme ended up being a lifeline for those living in the vast country's hinterlands. Beyond the limitations of their physical isolation, families that live off the grid now have access to clean and sustainable energy (Millison et al., 2022). This not only made living circumstances better but also made it possible for the villagers to use solar energy for useful purposes like running small enterprises and irrigating crops. Access to electricity became a steppingstone to overall upliftment in the development mosaic. The Mali-Folkecenter Nyetaa initiative illustrated how solar energy and healthcare are mutually beneficial. Vaccines and medications that needed continual chilling may now be preserved trustfully by installing solar-powered refrigeration units in healthcare facilities. This effort had far-reaching consequences that went beyond the health centres themselves since increased access to healthcare resulted in healthier neighbourhoods, lower illness loads, and ultimately higher quality of life. In rural and underdeveloped places, solar PV lamps are a beacon of possibility that serves as energy access rather than just a lightbulb. Beyond the walls of electrified houses, the consequences of energy access weave a tapestry of empowerment, resiliency, and optimism. Solar PV serves as a bridge to a more just and prosperous future as emerging nations work to close the energy gap.

Additionally, the adoption of solar photovoltaic (PV) technology in the field of renewable energy isn't simply a move towards sustainable power—it's also a driver for economic change. Solar PV adoption's ability to create a variety of employment across the whole value chain is one of its most alluring features. Solar energy's extensive influence on job creation, from manufacture and installation to maintenance and research, is a source of optimism, particularly for poor nations (Zhuo et al., 2021). A remarkable illustration of the employment potential of this technology comes from China, which is the world leader in the deployment of solar PV. The nation's industrial industry reached new heights thanks to the nation's ambitious solar targets. Due to the need for solar panels, manufacturing hubs were established, creating a large number of employments in production, quality control, and R&D. This contributed significantly to economic growth and helped millions of people escape poverty by creating steady work possibilities.

Germany serves as an example of how solar PV adoption has an impact on employment. Solar sector growth was sparked by the nation's steadfast commitment to the "Energiewende," or

shift to renewable energy. Jobs were produced in great numbers, from small-scale solar farms to massive rooftop solar installations. As the solar industry grew, jobs for engineers, technicians, salespeople, and even administrative positions prospered (Shaughnessy 2022). This wave of employment growth spread throughout the economy's diverse sectors, promoting a feeling of sustainable growth and communal empowerment. Kenya presents an interesting example from the African continent. Local solar businesses that specialise in both off-grid and grid-connected systems were established as a result of the Kenyan government's desire for more solar energy use. As a result, positions ranging from sales and marketing positions to technicians working on solar systems were created. Both urban and rural regions were able to take advantage of these job possibilities, which helped the country's economic development and efforts to fight poverty (Ditlev-Simonsen, 2022).

The solar home system programme in Bangladesh encouraged self-employment and entrepreneurship. Solar household systems were installed and maintained by local technicians who had received the necessary training, resulting in a network of experts who improved access to electricity while also boosting local economies. The development of the solar industry fostered an ecosystem of vendors, educators, and technicians, demonstrating how solar energy can foster a diverse labour market. The adoption of solar PV technology serves as a multiplier for employment growth across the value chain. Solar PV is a powerful force that illuminates chances for meaningful employment and helps to realize long-term development goals as developing nations look for methods to increase economic growth and reduce poverty (Thilanka et al., 2021).

Also, solar photovoltaic (PV) technology appears as a ray of hope amid urgent global environmental challenges, providing more than simply a source of energy—it offers a route to environmental renewal and sustainable growth. Solar PV's environmental advantages have wide-ranging consequences for tackling climate change and accomplishing the challenging goals of sustainable development since it can replace fossil fuels and reduce carbon emissions. Germany is a steadfast supporter of solar PV's environmental advantages. Significant reductions in greenhouse gas emissions were achieved as a result of the country's choice to invest extensively in renewable energy, especially solar. Germany made tremendous progress in weaning itself off fossil fuels as solar panels multiplied. This change not only promoted a cleaner energy mix but also established the nation as a world leader in the use of renewable energy sources (Shaughnessy 2022).

In Costa Rica, solar energy production and environmental preservation work in perfect harmony. The nation's dedication to sustainability enabled it to produce 100% renewable power for extended periods. Costa Rica decreased its dependency on imported fossil fuels while simultaneously reducing carbon emissions by making the most of its plentiful sunshine. This amazing achievement served as proof of the ability of solar photovoltaics to promote sustainable development while preserving natural resources. China, which is frequently linked to its fast industrialisation and environmental problems, exemplifies the revolutionary potential of solar PV. An increase in solar installations was caused by the country's attempts to switch to

greener energy sources. This huge shift made a considerable contribution to global efforts to mitigate climate change in addition to improving air quality and reducing dependency on coal (Millison et al., 2022). The essential significance of solar PV in defining a better future is shown by China's transformation from the world's greatest emitter of greenhouse gases to a leader in renewable energy (Adelakun and Olanipekun, 2019).

The Noor Ouarzazate Solar Complex in Morocco is an outstanding illustration of the potential of solar energy for environmental stewardship. The complex, one of the biggest solar power plants in the world, lessens Morocco's reliance on fossil fuels and thus lowers carbon emissions. This change is consistent with the country's resolve to lessen its carbon footprint and support international efforts to combat climate change (Mohamed and Touhami, 2020). The acceptance of solar PV technology is a tribute to the ability of human creativity to improve our connection with the environment, not just for the sake of generating electricity. Solar photovoltaic technology (PV) emerges as a beacon of hope as the globe struggles with the demands of climate change and sustainable development, providing a practical means to balance growth with environmental care.

Furthermore, solar photovoltaic (PV) technology plays an important role in the adoption of renewable energy sources since it not only solves urgent energy problems but also serves as a testing ground for new ideas. The difficulties encountered in the effort to adopt solar energy in developing nations act as fuel for creative solutions. The difficulties of solar adoption fuel technical innovation, guiding the trajectory towards cleaner, more sustainable energy futures (Dirk and Sven, 2021). These innovations range from ground-breaking technology to inventive finance structures and specialised commercial solutions.

A striking case study of technical innovation that emerged from the furnace of difficulties is Bangladesh. Due to a lack of available space, the country's densely populated metropolitan centres faced serious obstacles to the development of solar power. In response, businesses created ground-breaking solutions including rooftop solar systems and solar-powered charging stations (Huang, 2021). These specialised, cutting-edge methods, designed for urban settings, not only enhanced solar deployment but also cleared the door for greater access to electricity. In Kenya, where isolated people sometimes lack access to energy, is a prime example of how technology can overcome problems with conventional infrastructure. The introduction of mobile payment systems cleared the way for creative solar energy financing schemes. Pay-as-you-go systems made it possible for families to pay for solar systems over time, even if they lacked the initial investment. Energy access was revolutionised by this confluence of technology and money, demonstrating the transformational potential of innovation (Marina et al., 2020).

Technology-driven solutions have been essential in overcoming obstacles in India, a nation renowned for its diversified energy environment. The development of solar-powered microgrids has been crucial in bringing electricity to isolated villages and underserved areas. In combination with smart grid technology, these decentralised systems provide specialised solutions that get over the restrictions of conventional infrastructure growth and provide

dependable energy availability (Shaughnessy 2022; Acosta et al., 2016). Also, Tanzania serves as an example of how demand for energy solutions may encourage creativity. The lack of access to contemporary energy services in rural regions called for innovative solutions. Portable solar-powered lanterns and home systems were developed by businesses, revolutionising illumination and communication in off-grid settlements. These technical advancements enabled communities to harvest solar energy in creative ways while also acting as a lifeline for electricity access. The difficulties in implementing solar PV in poor nations are not insurmountable obstacles; rather, they serve as stimuli for technical advancement. Technology innovation emerges as a guiding light, showing a route towards a more sustainable and equitable energy future as the globe grapples with the challenges of switching to cleaner energy sources.

Concluding, developing counties are on the verge of a dramatic opportunity in the transition to sustainable energy. International help, in the form of loans, grants, technical support, and cooperative alliances, is a ray of hope, sparking the momentum required to spur the adoption of solar photovoltaic (PV) technology. The crucial role that international collaboration plays in promoting the deployment of solar energy, drawing conclusions from case studies that demonstrate the potential for cooperative efforts to expedite development and create a cleaner, more equitable energy environment (El-Haggar and Samaha, 2019).

International assistance has stoked the adoption of solar energy in Sub-Saharan Africa, providing a tragic backdrop for this development. An excellent example is the International Finance Corporation's (IFC) Scaling Solar programme. This programme encourages public-private partnerships to streamline project development procedures and lure private investment in nations like Zambia and Senegal. International organisations create the groundwork for solar projects that support energy access and economic growth by supplying technical know-how, supporting regulatory frameworks, and leveraging financial resources. Haiti, a country that struggles with energy poverty serves as an example of how international cooperation may be vital to sustainable development. The Solar Market Gardens project was started by the Solar Electric Light Fund (SELF), in collaboration with regional groups and foreign funders. This project increased agricultural production and improved livelihoods by using solar-powered water pumps, drip irrigation systems, and education programmes. Such cooperative initiatives highlight how global assistance may go beyond energy availability and spark other improvements.

The International Solar Alliance (ISA) is a prime example of the partnership between industrialised and poor nations. The ISA brings nations together to overcome issues associated with the development of solar energy, with an aim of mobilising over a trillion dollars in investment in solar projects by 2030. This project was led by France and India, showing how international collaboration can spur the expansion of the solar industry. The Green Climate Fund (GCF) is evidence of the dedication of international organisations to promoting the use of solar energy. The GCF supports programmes in poor nations that deal with climate mitigation and adaptation by offering financial and technical support. The GCF supports solar

programmes like Uganda's Rural Electrification Programme, advancing energy access and coordinating with more general sustainable development goals. The goals of developing countries are connected to the knowledge and resources of the global community via international support, which serves as a bridge. International collaborations enlighten the way, promoting resilience, empowering communities, and paving a common trajectory towards a more sustainable and inclusive world as poor nations traverse the challenging route towards cleaner energy futures.

CONCLUSION

The road towards solar photovoltaic (PV) adoption in underdeveloped nations stands out as a painful chapter in the enormous tapestry of global development, defined by obstacles, victories, and limitless promises. As we consider the many facets of this project, it becomes clear that, despite challenges casting shadows, opportunities and promises nonetheless shine through, paving the way to a future with cleaner, more sustainable energy sources.

The problems faced in the adoption of solar PV, which range from financial constraints to infrastructural constraints to governmental impediments, are not insurmountable. They are points of intersection when creativity, willpower, and teamwork merge to create new lanes. Through innovative financing arrangements, incentives, and joint investments, the financial complexities that formerly stood in the way of development are progressively being addressed. Infrastructure constraints have sparked the development of hybrid technologies, decentralised networks, and intelligent grids, fundamentally altering how energy is acquired and used. Transparent frameworks and progressive regulations that recognise solar energy's revolutionary potential are rapidly replacing regulatory obstacles.

Access to energy, the development of jobs, environmental protection, technical advancement, and international cooperation are all possibilities that glisten in the distance. Unmatched is solar PV's capacity to provide light in dark places, boost local economies, reduce carbon emissions, encourage innovation, and create international alliances. These factors combine to provide a strong argument for action and investment from individuals as well as from governments and organisations who understand the significance of this moment in determining the course of our planet's sustainable future.

Recommendations

As the horizon of solar PV adoption unfolds in developing countries, several recommendations emerge as guiding beacons, pointing towards a more effective and inclusive transition:

1. Inclusive Policy Frameworks: Governments should cultivate stable and supportive regulatory environments that foster private investments, innovation, and local entrepreneurship. Clear policy frameworks, incentives, and streamlined approval processes can significantly accelerate solar PV adoption.

2. Capacity Building: To overcome the lack of technical skills, funding training programmes, educational efforts, and skill development is essential. Long-term success depends on

equipping local populations with the information and abilities needed for solar PV installation, maintenance, and management.

3. Creative Financing: For communities with limited resources, solar PV systems may be financially feasible through the use of microloans, pay-as-you-go methods, and public-private partnerships. Financial assistance may be improved yet more by cooperation with international financial institutions and organisations.

4. Awareness and Education: Educational programmes and public awareness campaigns help clear up misunderstandings, advance comprehension, and foster a culture of accepting solar energy. Wider acceptance of solar technology may be facilitated by providing concrete instances of its advantages.

5. Joint Projects: The importance of foreign assistance cannot be emphasised. Collaborations with international organisations and partnerships between developed and poor countries can provide resources, knowledge, and momentum for solar energy initiatives.

In conclusion, the path towards the adoption of solar PV in poor nations is laced with potential, promise, and a need for coordinated action. The difficulties encountered are not obstacles to be surmounted, but rather stepping stones to creativity and advancement. We can blaze a way to a more sustainable, just, and powerful future for everyone by using the potential of solar energy. Governments, organisations, communities, and people working together in this effort add to a story of transformation, resiliency, and optimism that cuts beyond national boundaries and determines the course of the globe.

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