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CHALLENGES AND OPPORTUNITIES FOR DEPLOYING SOLAR ENERGY IN DEVELOPING COUNTRIES

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Abstract

This article examines the evolving landscape of solar energy adoption in developing nations, specifically within the context of smart cities. Developing nations must address the energy deficit, mitigate emissions, stimulate economic growth, and improve energy security. Solar energy presents viable solutions to these difficulties. Notwithstanding the potential of solar energy, challenges persist. Financial limitations, obsolete infrastructure, grid instability, deficiencies in technical skills, and regulatory obstacles impede extensive adoption. Nevertheless, advancements in solar panels, energy storage, smart grids, and data analytics offer solutions to these difficulties. Collaborative activities, uniform policies, and public-private partnerships provide assistance for sustainable development. Intelligent urban areas are pivotal in this transformation. Sustainable urban design, intelligent infrastructure, and digitalisation enhance the efficient utilisation of solar energy. Case studies from India, Rwanda, and Brazil illustrate the effective incorporation of solar energy into smart city initiatives. Reconciling problems with opportunities is essential for success. By overcoming challenges and capitalising on opportunities, developing nations can spearhead the transition to a sustainable energy future.

1.0 Introduction

As the 21st century has begun, a new era of unparalleled global challenges has begun, with climate change being at the forefront of this new landscape. It has never been more important to have

access to sustainable and renewable energy sources than it is right now, as the globe is struggling to cope with the terrible effects of rising temperatures, extreme weather events, and an impending environmental crisis. In light of the current predicament, solar energy has arisen as a ray of hope due to its capacity to supply power that is both pollution-free and abundant.
The implications of climate change are not immune to developing countries, and they frequently experience the most severe consequences as a result of these impacts. In addition, these countries are also experiencing rapid urbanisation, a process that brings forth a variety of challenges as well as benefits. The confluence of these two realities has resulted in the emergence of a significant matter of concern, which is the incorporation of solar energy into the framework of smart cities across developing countries.

2.0 Deploying Renewable Energy in Developing Countries

2.1The General Situation

When it comes to energy, developing countries are characterised by a number of issues that are interconnected with this issue. The problem of how to get access to energy comes first and foremost. There is still a sizeable section of their populations that does not have access to dependable power, which impedes the growth of their economies, threatens their quality of life, and undermines their educational chances. It is therefore of the utmost importance for these countries to discover methods that are both sustainable and capable of bridging the energy gap, and this is where solar power comes into play.

Furthermore, the development of solar energy is strongly aligned with the objectives of reducing the effects of climate change for the better. A transition to low-carbon energy sources is something that developing nations have a vested interest in doing because they are frequently disproportionately affected by climate-related disasters. A considerable reduction in emissions of greenhouse gases and a fight against global warming can be accomplished through the use of solar energy.

The solar energy industry has the potential to be a driver of job development and a reduction in the cost of electricity, from an economic point of view. It is possible that the continued decrease in the cost of solar technology will have the effect of bolstering local economies by encouraging a culture of innovation and entrepreneurship. Furthermore, the decreased costs of energy for businesses and people can free up resources that can be used to meet other essential requirements, which, in turn, can stimulate economic growth.

When it comes to many emerging countries, energy security is another serious worry. Frequently, these countries are highly dependent on the importation of fossil fuels, which are susceptible to swings in price as well as disruptions in supply. They are able to lessen their reliance on energy sources that are imported and improve their energy security if they develop their solar potential.

2.2 Challenges on the Road to Solar Energy Adoption

However, transitioning to solar energy is not without its challenges. Financing remains a major obstacle, with developing nations frequently constrained by limited financial resources for infrastructure development. Building the necessary solar infrastructure, including solar farms, distribution networks, and energy storage solutions, requires substantial upfront investments. Infrastructure and grid integration issues pose additional hurdles. Many developing countries have outdated energy infrastructure, which must be upgraded and modernized to accommodate the fluctuations in energy supply that are inherent to solar energy. Ensuring grid stability while integrating renewable sources is a complex and costly endeavour.

Moreover, there is often a lack of technical expertise in these regions, which can hinder the effective deployment and maintenance of solar energy systems. A skilled workforce is crucial for ensuring the long-term success of solar projects. On the policy front, inconsistent regulations, bureaucratic barriers, and a lack of clear incentives can further deter investment in solar energy. These regulatory hurdles can stifle growth and innovation in the sector.

In light of these challenges, the promotion of solar energy in developing countries is not a straightforward task. However, technological advancements, policy initiatives, and the concept of smart cities offer a glimmer of hope, providing opportunities to overcome these obstacles and usher in a new era of sustainable and resilient urban development. This perspective article delves deeper into these critical dimensions, aiming to provide a comprehensive understanding of the challenges and opportunities associated with solar energy adoption in the context of smart cities within developing nations.

2.3 Solar Energy in Developing Countries

Solar energy has become an indispensable player in the global effort to address energy challenges and foster sustainable development, particularly in developing countries. Understanding the multifaceted dimensions of solar energy adoption in these regions is essential, as it holds the key to a brighter, cleaner future.

2.4 Energy Access: Alleviating Energy Poverty

Energy poverty is a pressing issue in developing countries, affecting billions of people. Far too often, individuals and entire communities lack access to reliable and affordable electricity. In rural and remote areas, the absence of electricity hampers not only daily life but also the development of crucial sectors such as healthcare, education, and economic activities. The need for increased energy access is one of the most compelling reasons to embrace solar energy. Off-grid and decentralized solar solutions, including solar home systems and mini-grids, are empowering communities that were once left in the dark. These solutions provide an affordable and sustainable source of power, improving the quality of life, enhancing educational opportunities, and catalysing economic growth for those living in energy-starved regions.

Furthermore, access to energy is a driving force for gender equality. In many developing countries, women are disproportionately affected by energy poverty, as they are often responsible for household tasks like cooking, which can involve dangerous and polluting fuels. Solar energy can

reduce this burden by providing cleaner and safer cooking alternatives, thus empowering women and improving their overall well-being.

2.5 Obstacles to overcome on the path to widespread adoption of solar energy.

Changes to solar energy, on the other hand, are not without their difficulties. Developing countries usually face limitations in terms of the financial resources available for the development of infrastructure, which continues to be a significant hurdle. It is important to make significant initial expenditures in order to construct the necessary solar infrastructure, which includes solar farms, distribution networks, and alternatives for energy storage.

Concerns over grid interconnection and infrastructure combine to provide further obstacles. It is necessary to improve and modernise the energy infrastructure of many developing countries, which is obsolete, in order to tolerate the swings in electricity supply that are inherent to solar energy. An ambition that is both difficult and expensive to accomplish is ensuring grid stability while simultaneously integrating renewable sources.

The deployment and maintenance of solar energy systems might be made more difficult in these places due to the fact that there is frequently a deficiency of technical experience in these areas. It is absolutely necessary to have a skilled labour force in order to guarantee the long-term viability of solar projects. Another factor that can discourage investment in solar energy is the existence of contradictory legislation, bureaucratic obstacles, and a lack of clear incentives. These obstacles posed by regulations have the potential to hinder growth and innovation within the sector.

Solar energy promotion in underdeveloped countries is not an easy task to do because of the problems that are presented here. There is, however, a ray of optimism due to the fact that technological breakthroughs, legislative initiatives, and the concept of smart cities offer chances to overcome these challenges and usher in a new era of urban development that is both sustainable and resilient. The purpose of this viewpoint post is to provide a full knowledge of the obstacles and opportunities connected with the adoption of solar energy in the context of smart cities within developing nations. This paper goes deeper into these two essential factors.

Nigeria, the most populous nation in Africa, is experiencing a significant energy crisis that hampers its economic progress and diminishes the quality of life for its population.
Notwithstanding its extensive stocks of renewable energy resources, such as solar, wind, hydro, and biomass, the country largely depends on fossil fuels, particularly natural gas and oil, for electricity generation. The significant reliance on non-renewable resources has led to environmental deterioration, heightened greenhouse gas emissions, and an inconsistent power supply in both rural and urban areas (Sambo, 2009; Ohunakin et al., 2014).
The Nigerian energy sector is marked by frequent power outages, insufficient generation capacity, substandard transmission infrastructure, and elevated prices linked to fossil fuel energy production. According to the International Energy Agency (IEA, 2021), more than 90 million

2.6 Nigeria Energy Landscape

Over 40% of the Nigerian population lacks access to power. This energy shortfall impedes industrial productivity, discourages foreign investment, and intensifies socio-economic disparity.

In rural regions, the circumstances are becoming concerning, as power access rates dip below 30%, thereby constraining chances for education, healthcare, and small-scale company development (World Bank, 2022).

Nigeria's geographical and climatic conditions present ample prospects for the advancement of renewable energy. The nation averages solar radiation of 5.5 kWh/m²/day, totalling over 3000 hours of sunshine per year, positioning solar energy as one of its most potential renewable resources (Shaaban & Petinrin, 2014). The potential for wind energy is considerable in the northern regions, where average wind speeds surpass 5.0 m/s at a height of 10 meters. Hydropower resources, particularly small- and medium-scale hydro sites, are dispersed throughout Nigeria's river basins and remain predominantly unexploited (Ohunakin et al., 2014). Moreover, biomass derived from agricultural wastes and animal waste constitutes a sustainable energy source, especially for off-grid rural applications.

Notwithstanding these benefits, the implementation of renewable energy in Nigeria progresses sluggishly due to various obstacles. Factors include insufficient political will, feeble regulatory frameworks, restricted access to financing, inadequate technical proficiency, and low public awareness (IRENA, 2020). Investors are often deterred by inconsistent energy policies, volatile tariffs, and challenges in securing licenses and approvals. Moreover, the national grid is inadequately prepared to incorporate decentralised renewable energy systems, therefore constraining the potential for distributed generation (Sambo, 2009). Countries that have deliberately invested in renewable energy have experienced substantial advantages in energy accessibility, climate resilience, and employment generation. Kenya's investment in geothermal and solar energy has significantly enhanced rural electrification and stabilised energy prices (IRENA, 2020). These success narratives offer pertinent frameworks for Nigeria to embrace, modify, and expand to realise Sustainable Development Goal 7: cheap and clean energy for all. This study aims to investigate the obstacles impeding the advancement and implementation of renewable energy technologies in Nigeria. The study seeks to enhance the nation's sustainable and inclusive energy future by analysing current obstacles and pinpointing reform prospects. Confronting these difficulties is crucial for attaining energy security, minimising climate change, improving public health, and fostering socio-economic development.

2.7 Assessment of Renewable Energy Capabilities in Nigeria

Nigeria possesses vast renewable energy resources that, if efficiently utilised, may profoundly revolutionise its energy sector, diminish reliance on fossil fuels, and facilitate socio-economic growth. Renewable sources—solar, wind, hydro, and biomass—are naturally and geographically dispersed throughout the country, providing many alternatives for both decentralised and gridconnected applications. The sun energy is likely the most potential renewable resource in Nigeria, given the country's position inside the high sun radiation belt of sub-Saharan Africa. The country averages a solar insolation of 5.5 kWh/m²/day and undergoes approximately 3,000 hours of sunlight each year (Sambo, 2009). This degree of solar radiation renders both photovoltaic (PV) and concentrated solar power (CSP) technologies feasible for energy production, particularly in rural and off-grid regions.

Recent government initiatives, including Nigeria's Solar Power Naija program, seek to capitalise on the capacity to enhance energy accessibility and diminish dependence on diesel generators. The potential for wind energy is primarily located in the northern regions, where wind speeds vary from 4.0 to 5.1 m/s at a height of 10 meters (Sambo, 2009). This range is appropriate for small to medium-scale wind turbines and is adequate for powering community microgrids, irrigation systems, and rural health facilities. Wind mapping studies have highlighted locations in states such as Sokoto, Katsina, and Borno as favourable for pilot wind energy initiatives.
Hydropower continues to be an essential component of Nigeria's energy portfolio. The nation possesses an estimated minor hydropower potential over 3,500 MW, distributed across its various rivers and streams (Ohunakin et al., 2014). Although large-scale hydroelectric facilities like Kainji and Shiroro are operational, tiny and mini-hydro systems are attracting interest due to their reduced environmental effects and appropriateness for isolated populations.

Nigeria produces around 144 million tonnes of biomass annually from agricultural residues, forestry by-products, and animal wastes (Shaaban & Petinrin, 2014). These materials can be transformed into biofuels, biogas, and briquettes, providing clean options for cooking, heating, and electricity generation. Notwithstanding these considerable potentials, practical implementation is constrained by infrastructural, regulatory, and financial obstacles that the nation must overcome to achieve a sustainable energy future.

3.0 The Contribution of Solar Energy to Developing Countries

In the worldwide effort to address energy concerns and support sustainable development, particularly in poor countries, solar energy has emerged as a crucial component; it has become a vital actor. In order to have a more positive and environmentally friendly future, it is vital to have a multidimensional understanding of the various aspects of solar energy adoption in these locations.

3.1The Elimination of Energy availability Through Improvements in Energy Access There are billions of individuals who are affected by energy poverty, which is a major issue in developing countries. The lack of access to dependable and reasonably priced energy is a problem that affects individuals and entire communities as well. Lack of access to electricity not only makes day-to-day life more difficult in rural and isolated locations, but it also impedes the growth of essential industries like healthcare, education, and economic activity. One of the most persuasive arguments in favour of solar energy is the current demand for increasing access to energy sources. Solar solutions that are off-grid and decentralised, such as solar household systems and mini-grids, are giving communities that were previously without access to electricity the ability to become self-sufficient. For those who live in areas that are lacking in energy, these solutions offer a source of electricity that is both inexpensive and sustainable, which in turn improves the quality of life, expands educational opportunities, and stimulates economic growth.

A further factor that contributes to the advancement of gender equality is the availability of electricity. They are generally responsible for domestic duties such as cooking, which can require fuels that are hazardous and polluting. As a result, women are disproportionately affected by energy poverty in many developing nations. Solar power has the potential to alleviate this burden

by offering alternatives to cooking that are both cleaner and safer. This would result in women gaining more power and an overall improvement in their health.

3.3 Environmental Benefits: Addressing Climate Change.

The ecological advantages of solar energy surpass just electricity generation. Developing nations, akin to the global community, are contending with the ramifications of climate change, which encompass increased frequency and intensity of meteorological phenomena, altered precipitation patterns, and agricultural disruptions. By embracing solar energy, these nations aid the worldwide initiative to diminish greenhouse gas emissions and alleviate climate change.

The minimal carbon footprint of solar energy renders it an essential resource in combating global warming. Photovoltaic systems capture solar energy without releasing greenhouse gases, rendering them a sustainable and environmentally benign energy source. By substituting fossil fuels for power generation, solar energy mitigates detrimental air pollutants, enhancing air quality and public health. This shift to cleaner energy corresponds with global climate accords and establishes a framework for developing nations to diminish their emissions and exemplify responsible energy stewardship.

3.3 Economic Advantages: Employment Generation and Expense Minimisation

The economic advantages of solar energy implementation are dual-faceted. The sector offers substantial prospects for employment generation. The installation, maintenance, and production of solar panels and associated technologies can create job possibilities, especially in areas with significant solar potential. These positions encompass a range of skill levels, from technicians to engineers, enhancing local economies and livelihoods.

Secondly, solar energy presents the opportunity for decreased energy expenses for both individuals and enterprises. As the price of solar technology decreases, electricity produced from solar sources becomes progressively competitive with traditional energy sources. This decrease in energy costs liberates resources that can be redirected to other vital necessities, such as education, healthcare, and infrastructure development. Reduced energy expenses for enterprises also bolster competitiveness and profitability, consequently fostering economic growth and elevating living standards.

3.3.1 Energy Security: Mitigating Reliance on Fossil Fuels

Developing nations frequently depend significantly on imported fossil fuels, rendering their economies vulnerable to fluctuating worldwide oil prices and geopolitical uncertainties. The reliance on fossil fuel imports might result in adverse economic effects and impede overall energy security. Solar energy presents a solution by supplying a local, native, and sustainable power source. By diversifying their energy portfolio with solar power, developing nations can mitigate their susceptibility to foreign energy supply interruptions and price volatility. The deployment of solar energy enhances energy security, stabilises energy availability, and fosters economic resilience and independence.

Additionally, solar energy can be utilised in decentralised systems, like rooftop solar panels and microgrids, enabling small communities to produce their own electricity. The decentralisation of

energy production diminishes dependence on centralised power plants and extensive transmission links, hence augmenting energy security and resilience.

In conclusion, solar energy's significance in developing nations extends beyond a mere transition in energy sources; it constitutes a crucial advancement in tackling energy accessibility, environmental sustainability, economic growth, and energy security. Energy poverty, climate change, and economic inequities present concerns that are uniquely addressed by solar energy options. By capitalising on these prospects, developing nations may revolutionise their energy frameworks, promote sustainable development, and provide a more promising, cleaner future for their populations.

4.0 Challenges in Solar Energy Adoption.

Although the advantages of solar energy in developing nations are significant, various obstacles must be addressed to achieve its complete potential. These challenges include financial limitations, obsolete infrastructure, inadequate technical proficiency, and intricate policy and regulatory frameworks.

4.1 Financing: Scarce Financial Resources for Infrastructure Development

A major obstacle to the extensive adoption of solar energy in underdeveloped nations is the restricted availability of financial resources. Establishing the requisite solar infrastructure necessitates significant initial expenditures in solar panels, inverters, energy storage devices, and distribution networks. Although the long-term economic advantages are clear, securing the initial funding to finance such initiatives presents a significant barrier. Government budgets frequently experience constraints, while the private sector may exhibit reluctance to invest owing to perceived risks and uncertainties.

Addressing this financial disparity requires innovative funding strategies. These may encompass public-private partnerships, international development assistance, concessional loans, and the creation of specialised funds for renewable energy initiatives. Implementing efficient finance solutions can enhance the adoption of solar energy infrastructure, rendering it more accessible to a wider demographic and a diverse array of investors.

4.2 Infrastructure and Grid Integration: Obsolete Infrastructure and Grid Unreliability The current energy infrastructure in numerous developing nations is antiquated and inadequately prepared to handle the fluctuating and decentralised characteristics of solar energy. Solar generation is sporadic, and grid instability may arise if the infrastructure fails to accommodate the variations in power supply. This poses a dual challenge: the modernisation of the electrical grid and the integration of smart grid technologies to facilitate the smooth assimilation of renewable energy sources.

Enhancing infrastructure necessitates considerable money and time. Nonetheless, it is crucial for the efficient incorporation of solar energy into the energy portfolio. The shift to a smart grid, featuring real-time monitoring and control functionalities, can improve grid stability, facilitate efficient energy distribution, and reduce energy losses during transmission.

Microgrid systems are feasible alternatives for distant and off-grid regions, as they can function autonomously or in cooperation with the primary grid. These microgrids provide localised energy generation and distribution, enhancing resilience to external grid disruptions and bolstering energy security.

4.3 Deficiency in Technical Proficiency: Inadequate Training and Knowledge

Solar energy systems necessitate specialised technical proficiency for installation, maintenance, and optimal functioning. Regrettably, numerous developing nations encounter a deficiency of skilled professionals in this domain. Inadequate training and understanding may yield inadequately built and maintained solar installations, resulting in diminished performance, elevated costs, and a shortened system lifespan.

Resolving this issue necessitates investment in training and educational programs for local technicians, engineers, and maintenance staff. By offering extensive training and certification programs, nations may cultivate a proficient workforce capable of assuring the efficient functioning of solar energy systems. This investment in human capital not only fosters the sustainability of solar initiatives but also generates employment possibilities, so bolstering economic growth.

4.4 Policy and Regulatory Obstacles: Inconsistent Policies and Regulations

Ambiguous and inconsistent policies and regulations can foster an adversarial atmosphere for the deployment of solar energy. Frequent policy alterations, bureaucratic obstacles, and an absence of standardised standards might dissuade investors and impede project development. The lack of clearly defined incentives, subsidies, and feed-in tariffs may further dissuade solar energy ventures.

An extensive and clear regulatory framework is crucial for ensuring clarity and stability in the solar energy sector. Governments ought to formulate and execute supportive policies that provide incentives and subsidies to promote investment in solar initiatives. Regulatory agencies must collaborate with industry stakeholders to establish a conducive climate that promotes project development, safeguards investor interests, and enables a seamless transition to solar energy.

In conclusion, although the potential of solar energy in developing countries is substantial, these governments must confront a range of intricate problems to fully capitalise on its benefits. Addressing financial obstacles, upgrading infrastructure, cultivating technical proficiency, and establishing conducive policy frameworks are essential measures in the pursuit of sustainable and resilient solar energy implementation. Confronting these problems will expedite the shift to clean and dependable energy sources, while also fostering economic growth and enhancing the quality of life for numerous citizens in emerging areas.

5.0 Impediments to Solar Energy Adoption.

Despite the considerable benefits of solar energy in developing countries, numerous challenges must be overcome to realise its full potential. The problems encompass financial constraints, outdated infrastructure, insufficient technical expertise, and complex legislative and regulatory frameworks.

5.1 Financing: Inadequate Financial Resources for Infrastructure Development

A significant barrier to the widespread implementation of solar energy in developing countries is the limited access to financial resources. Establishing the necessary solar infrastructure requires substantial initial investments in solar panels, inverters, energy storage systems, and distribution networks. Despite the evident long-term economic benefits, obtaining the initial capital to support such ventures constitutes a considerable obstacle. Government budgets often face limitations, whilst the private sector may hesitate to invest due to perceived risks and uncertainties. Mitigating this financial inequity necessitates inventive funding approaches. These may include public-private partnerships, international development aid, concessional loans, and the establishment of specialised funds for renewable energy projects. Implementing effective financial solutions can facilitate the adoption of solar energy infrastructure, making it more accessible to a broader demography and a varied range of investors.

5.2 Infrastructure and Grid Integration: Outdated Infrastructure and Grid Instability The existing energy infrastructure in many developing countries is obsolete and insufficiently equipped to manage the variable and decentralised nature of solar energy. Solar energy is intermittent, and grid instability may occur if the infrastructure cannot adapt to fluctuations in power supply.

This presents a twofold challenge: the upgrading of the electrical infrastructure and the integration of smart grid technologies to enable the seamless incorporation of renewable energy sources. Improving infrastructure requires substantial financial resources and time. However, it is essential for the effective integration of solar energy into the energy portfolio. The transition to a smart grid, equipped with real-time monitoring and control capabilities, can enhance grid stability, enable efficient energy distribution, and minimise energy losses during transmission.

Microgrid systems are viable alternatives for remote and off-grid areas, as they can operate independently or in conjunction with the main grid. These microgrids provide localised energy generation and distribution, improving resilience against external grid disturbances and strengthening energy security.

5.3 Deficiency in Technical Proficiency: Insufficient Training and Knowledge

Solar energy systems require specialist technical expertise for installation, maintenance, and maximum performance. Unfortunately, many emerging countries face a shortage of trained workers in this field. Insufficient training and comprehension may lead to poorly constructed and maintained solar installations, resulting in reduced performance, increased expenses, and a decreased system lifespan.

Addressing this issue requires investment in training and educational initiatives for local technicians, engineers, and maintenance personnel. Nations can develop a skilled workforce capable of ensuring the efficient operation of solar energy systems by providing comprehensive training and certification programs. This investment in human capital not only promotes the sustainability of solar ventures but also creates employment opportunities, hence enhancing economic growth.

5.4 Policy and Regulatory Barriers: Inconsistent Policies and Regulations

Ambiguous and contradictory policies and regulations might create a hostile environment for the implementation of solar energy. Frequent legislative changes, bureaucratic hurdles, and a lack of defined criteria may deter investors and hinder project advancement. The absence of explicitly specified incentives, subsidies, and feed-in tariffs may further deter solar energy initiatives.

A comprehensive and transparent regulatory framework is essential for providing clarity and stability in the solar energy sector. Governments should develop and implement supportive policies that offer incentives and subsidies to encourage investment in solar projects. Regulatory agencies must cooperate with industry stakeholders to create an environment that fosters project development, protects investment interests, and facilitates a smooth transition to solar energy.

In conclusion, while the potential of solar energy in developing nations is significant, these governments must address a variety of complex challenges to properly harness its advantages. Mitigating financial barriers, enhancing infrastructure, developing technical expertise, and instituting favourable legislative frameworks are critical actions for achieving sustainable and resilient solar energy deployment. Addressing these issues can accelerate the transition to clean and reliable energy sources, while simultaneously promoting economic development and improving the quality of life for many individuals in developing regions.

6.0 Case Studies

The practical application of solar energy adoption and smart city programs in several developing nations offers significant insights into the problems, opportunities, and policy strategies that have proven beneficial in promoting sustainable urban development. We examine case examples from Nigeria, India, Rwanda, and Brazil, emphasising significant initiatives and their effects.

6.1 Nigeria: Examples include a study on using solar PV to replace diesel generators in Lagos, an analysis of solar energy integration into a rural community grid in the Niger Delta, and a case study of the Solar Sister program that empowers women entrepreneurs. Other studies examine the overall solar potential, affordability, and policy frameworks in Nigeria.

Case studies and research on Nigerian solar programs

- *Solar PV for replacing diesel generators*: A case study focusing on Lagos, Nigeria, demonstrates how solar PV systems can reduce or eliminate the use of diesel generators, leading to significant cost savings over the project's lifetime.
- *Rural electrification and grid integration*: A study in the Umuezerokam community in the Niger Delta analyzes the feasibility and performance of integrating solar energy into the national grid to improve electricity supply in rural areas.
- *Solar Sister program*: This case study examines the activities of the Solar Sister program in Nigeria, which focuses on training and supporting women entrepreneurs in the clean energy sector.
- *Solar energy potential and development*: This research provides an overview of Nigeria's abundant solar energy potential and outlines a roadmap for developing it sustainably, acknowledging the challenges and opportunities involved.

- *Policy review and market analysis*: Several papers provide reviews of solar energy policies and their impact on market development, including analyses of the current status, affordability, and challenges of solar PV electrification in Nigeria.
- *Profitability and business strategies*: A case study explores the profitability strategies used by solar energy businesses in Lagos, Nigeria.

6.2 India - The Solar Cities Initiative (Ministry of New and Renewable Energy, Government of India, "Solar Cities," *mnre.gov.in*, The Energy and Resources Institute (TERI), "Solar Cities in India," *teriin.org*)

The Solar Cities program in India is a holistic endeavour aimed at advancing solar energy and sustainability in urban environments. Initiated by the Ministry of New and Renewable Energy, the initiative seeks to convert designated communities into "Solar Cities" by the incorporation of solar technology into multiple facets of urban living.

Principal Characteristics and Effects: The program promotes the installation of solar panels on rooftops to produce sustainable energy for residences, enterprises, and public facilities.

- Solar Street Lighting: Solar-powered streetlights diminish energy usage and improve safety in metropolitan environments.
- Renewable Energy Awareness: Public awareness initiatives and educational activities enlighten citizens regarding the advantages of renewable energy and sustainable practices.
- Waste-to-Energy Initiatives: Certain Solar Cities have executed waste-to-energy initiatives, transforming organic waste into biogas and power.
- The program incorporates solar energy solutions into urban design, facilitating the adoption of sustainable practices in transportation, building, and waste management by communities. The Solar Cities Initiative illustrates India's dedication to promoting sustainable urban development via solar implementation and clean energy initiatives. Through the utilisation of public awareness and governmental backing, the program has achieved significant advancements in converting cities into centres of renewable energy.

6.3 Rwanda - The Kigali Innovation City Initiative (Rwanda Development Board, "Kigali Innovation City," *rdb.rw*, GreenBiz "Africa's Silicon Valley: Rwanda's Ambitious Plan for Smart Cities"*greenbiz.com*)

The Kigali Innovation City project in Rwanda is an ambitious endeavour aimed at establishing a knowledge-based economy and fostering sustainable development. It integrates renewable energy, smart city principles, and digital infrastructure.

Principal Characteristics and Effects:

The project emphasises sustainable construction and green building approaches to minimise energy use.

- *Solar Energy Integration*: Photovoltaic panels are affixed to structures to produce sustainable electricity for municipal functions.
- *Smart Mobility*: The initiative encompasses the establishment of a public transit network and infrastructure for electric automobiles. Kigali Innovation City emphasises digital connectivity

and digitalisation, fostering technology-driven innovation. The project seeks to establish Rwanda as a technological centre in Africa, highlighting the capacity of solar energy and smart city initiatives to foster economic growth and sustainable development.

7.0 Opportunities and Prospective Outlook

The prospects offered by solar energy implementation in developing nations are extensive and possess the capacity to induce disruptive alterations throughout several sectors. The future prospects for solar energy in these areas are favourable, encompassing rural electrification, energy for productive applications, the generation of green employment, and technology advancements that could transform energy distribution.

8.0 Rural Electrification: Expanding Solar Accessibility to Isolated Regions

Rural electrification is a critical objective in numerous developing nations. Solar energy is a viable means to enhance electricity accessibility in remote and neglected areas. Off-grid and decentralised solar solutions, such as solar household systems and mini-grids, are significantly impacting communities by delivering reliable and sustainable power to those previously without access. These programs enhance the quality of life in rural regions by facilitating illumination, communication, and access to information, while also stimulating economic activities. They facilitate agricultural practices, improve education and healthcare facilities, and support smallscale companies, thereby narrowing the urban-rural development disparity.

8.1 Energy for Productive Applications: Assisting Agriculture and Small Enterprises

The promise of solar energy transcends mere electrification. It can be utilised to bolster agriculture and small enterprises, especially in rural regions. Solar-powered irrigation systems facilitate efficient crop watering for farmers, hence enhancing agricultural output and income. Solar cold storage facilities prolong the shelf life of agricultural products, minimising post-harvest losses. Moreover, small and medium-sized firms (SMEs) can leverage solar energy solutions, which provide dependable and economical power sources. Solar water pumps might be essential for enterprises in the food processing sector, enabling them to enhance operational efficiency and decrease energy expenditures. These applications are essential for economic development and employment generation in emerging regions.

8.2 Green Employment: Prospects for Employment and Entrepreneurship

The solar energy sector offers significant prospects for employment and entrepreneurship. As solar technology becomes increasingly economical and attainable, the demand for proficient individuals in solar installation, maintenance, and manufacture is escalating. This labour increase fosters economic progress and enhances livelihoods in developing nations.

Furthermore, the solar sector promotes entrepreneurship and domestic production, enhancing economic self-sufficiency. Small-scale solar firms, including solar panel assembly or distribution, can prosper and cater to local markets. Moreover, solar-powered micro-enterprises, including phone charging stations, generate economic prospects in off-grid regions.

8.3 Technological Innovations: The Impact of AI and Blockchain on Energy Distribution The advancement of solar energy in emerging nations is intricately linked to technological innovations.

Artificial intelligence (AI) and blockchain technology are set to transform energy distribution and management. This will be accomplished through the following:

1) *Artificial Intelligence for Energy Optimisation*: AI systems can enhance energy generation, distribution, and consumption efficiency. Machine learning algorithms can forecast energy demand and align it with solar generation, ensuring optimal electricity utilisation. This technology is essential for smart grids and microgrids, particularly in regions with sporadic energy sources.
2) *Blockchain for Decentralised Energy Trading*: Blockchain technology enables peer-to-peer energy trading, allowing individuals and enterprises to directly buy and sell surplus solargenerated electricity. The notion of decentralised energy trading fosters energy self-sufficiency and bolsters energy security in regions with unstable grid connections. The amalgamation of AI and blockchain in solar energy management enhances customer empowerment, fortifies grid resilience, and mitigates energy losses during distribution. It additionally facilitates the shift to clean and sustainable energy sources.

The future prospects for solar energy in developing nations are marked by a transition towards equitable and sustainable development. It has prospects for electrifying rural regions, improving agricultural efficiency, generating green employment, and implementing advanced technology to optimise energy delivery. These advancements enhance community well-being while fortifying the resilience and economic sustainability of these places, so securing a more promising and sustainable future.

9.0 Additional surveys and research

Renewable energy initiatives, especially in rural areas of developing countries, are essential for meeting global energy demands and fostering sustainability. The acceptance and long-term sustainability of such programs rely on a complex interplay of elements. This review article examines a number of studies from a systems thinking perspective to elucidate this complex subject. By comprehending these dynamics, we intend to offer significant insights into how renewable energy efforts might be more easily adopted and maintained within various contexts.

9.1 Principal study domains and subjects pertaining to solar energy deployment in developing nations

Topic1: Sustainability in solar energy projects(Garraín & Lechón, 2023):
Findings: A sustainability study mitigates adverse effects on environmental, social, and economic dimensions. Both LCA and MRIO possess inherent limitations. - IO analysis can yield varying outcomes and influence sustainability objectives.
Conclusions: Scientific frameworks such as FISA are crucial for decision-makers. - Precise objectives, parameters, and metrics are essential. - Solar energy is essential for achieving sustainable development objectives.

Topic 2: Solar energy's contribution to sustainable development objectives (Obaideen et al., 2021).
Findings: Solar energy facilitates the achievement of SDGs by reducing carbon emissions, enhancing power capacity, lowering costs, and providing home energy. - The MBR Solar Park in

Dubai is of considerable importance. The park evaluates diverse solar technology; Conforms to Dubai's 2050 strategy for renewable energy.
Conclusion: Solar energy is crucial for a sustainable future. The MBR Solar Park demonstrates the viability of ambitious solar initiatives.

Topic 3: The environmental performance of solar energy systems varies, with thin-film CIS exhibiting reduced impacts (Milousi et al., 2019).
Findings: The factors of efficiency, area, and cost vary among photovoltaic systems. - Flat plate methods are economically viable in specific climates.
Conclusions: Diverse photovoltaic technologies provide comparable energy output and emissions mitigation. - Flat plate methods are economically viable in certain climes.

Topic 4: The capacity of solar energy to mitigate emissions (Shahsavari et al., 2018)
Findings: Proposals to mitigate obstacles, encompassing subsidies, feed-in tariffs, and loans; International assistance, tax incentives, and proficient labour forces are crucial; Carbon price can incentivise the adoption of clean energy; Promoting awareness of environmental consequences is essential.
Conclusion: Constructive methodologies and political tactics are essential for the advancement of solar energy; Subsidies, feed-in tariffs, and loans promote renewable energy; Global collaboration and financial support are necessary; Tax incentives and carbon pricing facilitate the advancement of sustainable energy; Competent labour forces and research and development incentives are essential for the progression of solar technology; Promoting awareness of environmental issues is essential.

Topic 5: Solar Energy and Rural Development in Developing Countries (Ramakumar, 1977)
Findings: Advocate for a slow, incremental implementation of energy solutions in rural regions; Employ "intermediate technology" that corresponds with the economic constraints of poverty; Create rural energy centres to address fundamental needs and educational requirements; Establish local government initiatives to facilitate rural development; Mitigate rural unemployment by establishing energy centres.
Conclusion: Rural development should emphasise the incremental adoption of energy resources; Technology ought to be appropriate for societies with a surplus of workers; Rural energy centres can provide employment and enhance rural living conditions; Robust rural development is essential for comprehensive societal welfare.

Topic 6: Urban Design for a Sustainable Energy Future (Vandevyvere &Stremke, 2012)
Findings: Minimising energy use is a primary goal in the shift to renewable resources; Urban characteristics significantly influence the reduction of demand; The optimisation of energy flows is crucial for exergy enhancement, and; Renewable energy ought to satisfy the residual demand across many scales.
Conclusion: Decreasing energy consumption is a fundamental measure for achieving a green energy future; Urban morphology and exergy optimisation are essential factors; Renewable energy ought to supplement residual energy requirements across various sizes, and; Interdisciplinary research and application are essential for sustainable urban development.

Topic 7: The influence of socio-cultural factors on solar power adoption (Lin & Kaewkhunok, 2021)

Findings: The age of household heads positively affects the adoption of solar power. - Elderly household heads exhibit a greater propensity to utilise solar technology; Household income affects adoption rates; higher-income households exhibit greater adoption; Elevated educational attainment of household heads favourably influences adoption; Access to financing positively impacts adoption; Rural households exhibit a higher propensity to adopt solar power compared to their urban counterparts; Households lacking grid connection are more inclined to adopt solar energy; Adoption differs by developmental region, and; Adoption differs among ecological regions, and; Ethnic significantly influences adoption.

Conclusion: Socio-cultural issues, and inter-ethnic disputes, substantially influence the adoption of solar power technologies; Policymakers must take into account socio-cultural issues and advocate for equality via education and institutions to guarantee equitable access to contemporary energy technology.

Topic 8: Social acceptability of solar energy in Finland (Hai, 2019).

Findings: It is categorised into four levels of willingness to adopt: active willingness, unconditional willingness, conditional willingness, and unwillingness; Various client groupings are delineated according to these states, and; Social acceptance is classified into adoption, acceptance in principle, rejection, and opposition. Factors influencing adoption to promote uptake across diverse client segments.

Conclusions: To expedite the adoption of solar energy in Finland, it is crucial to address the varying levels of willingness and client segments with customised information and assistance; and; Policies and strategies must take into account both pre-adoption and post-adoption phases.

Topic 9: Causal Loop Diagrams Pertaining to the Acceptance of Renewable Energy Source Projects (González et al., 2016)

Findings: This section displays five causal-loop diagrams illustrating the primary factors that determine the sustainability and acceptance of renewable energy system projects within rural areas. The graphics were created within the confines of five distinct livelihood capitals: social, human, physical, natural, and financial.

Conclusion: Comprehending the intricate relationships among many livelihood capitals is essential for the success of renewable energy initiatives in rural communities. Interventions must be comprehensive, culturally attuned, and account for various characteristics of the community. Engaging the community, delivering education, and guaranteeing access to financial services are essential for project sustainability.

Topic 8.1: Social Capital -Positive Relationship

Findings: Networks and trust affect community adoption of renewable energy system projects.

Conclusion: Community acceptance is contingent upon social capital.

Topic8.2: Human Capital: Access to superior education and technology augments human capital. Energy deficiency impairs critical services.

Conclusion: Access to education and technology is essential.

Topic 8.3: Physical Capital
Findings: Fundamental infrastructure is essential for education, healthcare, and economic creation. Energy accessibility boosts community appeal.
Conclusion: Infrastructure is crucial for development and project approval.

Topic 8.4: Natural Capital - Environmental Quality.
Findings: Renewable Energy System initiatives may negatively impact the natural environment. Both direct and indirect effects must be taken into account.
Conclusion: Renewable energy sources can impact the environment, hence affecting public acceptance.

Topic8.5: Monetary Resources
Findings: Monetary resources can yield revenue; but, access to financial services is essential. Payment structures ought to mitigate risk.
Conclusion: Financial resources and credit accessibility are essential for project success.

9.0 Conclusion

Developing nations encounter unique obstacles in adopting solar energy; nonetheless, the potential for sustainable growth and advancement is substantial. The shift to clean energy sources becomes more attainable as smart cities play a crucial role in this transition. Technological advancements, the enactment of supportive legislation, and international collaboration have highlighted the promise of solar energy in underdeveloped countries. By adeptly tackling these issues and seizing the available opportunities, these nations are positioned to spearhead a future that is both more sustainable and energy-secure.

Principal Outcome of this study include:

1) Energy Transition in Developing Nations: Developing countries possess the opportunity to bypass traditional energy infrastructures and directly adopt renewable sources such as solar, thereby providing sustainable and reliable power for their inhabitants.
2) The implementation of solar energy in these places enhances environmental sustainability while concurrently fostering economic growth, generating employment opportunities, and promoting social advancement through improved access to key services.
3) The creation of smart cities serves as a catalyst, promoting innovation and efficiency while enhancing the effectiveness and accessibility of solar energy integration.
4) Technology and infrastructure Advancements: Accelerated technology innovation and infrastructure enhancement are propelling solar energy usage, decreasing costs, and enhancing energy accessibility for isolated populations.
5) Supportive policies and international cooperation are crucial facilitators of solar energy expansion, offering vital frameworks and investment prospects.
6) Resilience and Energy Security: Solar energy improves energy resilience, mitigating susceptibility to supply disruptions and strengthening energy security.

These findings emphasise the significant potential of solar energy in developing nations, where the integration of technology advancement, smart city initiatives, favourable regulations, and international collaboration facilitates a more sustainable and promising future. In light of urgent

energy and environmental issues, these nations are positioned to lead in the development of a robust, secure, and sustainable global energy framework.

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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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