Overcoming Barriers to Energy Access in Developing Countries: Lessons Learned from Household Solar Energy Systems in Bangladesh

Wen Li *

Earth and Environment, University of Leeds, Leeds, LS2 9JT, United Kingdom

* Corresponding author: ee22w2l@leeds.ac.uk

Abstract. In recent years, the focus has intensified on achieving Sustainable Development Goal 7 (SDG 7), which aims to ensure universal access to affordable, reliable, and sustainable modern energy. This dissertation delves into the challenges and opportunities faced by developing nations in pursuing SDG 7, emphasizing its global significance within the context of sustainable development goals. Critical issues such as energy poverty, unreliable energy supplies, and governance barriers are identified, highlighting the essential role of modern energy in fostering social equity, economic growth, and environmental protection. Through an in-depth analysis of successful solar home system implementation in Bangladesh, this research provides concrete examples of how governments, community engagement, and technological innovation can overcome these challenges. Sustainable energy solutions lead to improved access, reduced environmental pollution, and socio-economic development. In conclusion, collaborative efforts among governments, international organizations, and civil society are paramount for SDG 7 achievement. Strategies to overcome obstacles, including policy innovation, technology advancement, financial support, capacity building, and international cooperation, are outlined. This research informs policymaking, societal awareness, and research in sustainable energy, contributing to a broader understanding of how developing countries can address energy challenges and highlighting the importance of sustainable energy for global progress and well-being.

Keywords: Sustainable development, modern energy, energy poverty, solar home systems, barriers to development.

1. Introduction

Sustainable development has gained global attention, with the United Nations' Sustainable Development Goals (SDGs) playing a central role in promoting worldwide social, economic, and environmental sustainability [1]. Among these goals, SDG 7 is notable for its focus on ensuring that everyone has access to affordable, dependable, and sustainable modern energy. This is considered a fundamental element in advancing fairness in society, stimulating economic growth, and safeguarding the environment. The UN's 2030 Sustainable Development Agenda places an increased emphasis on the adoption of renewable energy sources, particularly wind and solar power projects, which are seen as promising energy options in developing nations [2]. However, realizing SDG 7 in these countries is beset with numerous challenges. Issues such as underdeveloped energy infrastructure, unreliable energy sources, technological and financial limitations, as well as policy and governance hurdles, make the promotion of sustainable energy a complex and demanding endeavor. Energy poverty, especially in rural parts of developing nations, has become increasingly evident, limiting people's access to steady and dependable energy sources, consequently impeding their quality of life and development prospects. Addressing energy poverty in developing nations is a multifaceted problem that has garnered significant attention from researchers and international bodies, including the United Nations (UN), the International Energy Agency (IEA), the International Atomic Energy Agency (IAEA), and the World Bank. Given that energy is central to economic progress, tackling energy poverty is an inherently political process and a vital component of the 2030 Sustainable Development Agenda [3].

Bangladesh, as a developing nation, has presented a tangible example through its Solar Home

System initiative, showcasing the feasibility of promoting sustainable energy within a complex setting. By means of policy backing, community participation, and technological innovation, Bangladesh has delivered cost-effective and dependable solar electricity to rural inhabitants [4]. This successful experience not only furnishes insights into addressing energy poverty but also imparts valuable lessons to other developing countries striving to attain SDG 7.

The objective of this article is to investigate the challenges encountered by developing nations in pursuing SDG 7, using Bangladesh's Solar Home System program as a foundational case study. Through an exhaustive examination, we aim to offer valuable strategies and measures for surmounting these challenges and contribute to the policy-making endeavors of developing countries, international organizations, and society at large in advancing sustainable development.

2. Barriers to Achieving SDG 7 in Developing Countries

2.1. Definition and Impact of Energy Poverty

In 2010, the World Economic Forum introduced the concept of energy poverty, characterizing it as the absence of access to contemporary, sustainable energy services and products. To provide a more precise definition, it's important to understand that energy poverty isn't solely a sustainability concern; it can manifest wherever there is an insufficient supply of affordable, reliable, high-quality, safe, and environmentally responsible energy services that foster development [5]. In many developing nations, a significant portion of the population still relies on traditional bioenergy sources like firewood and coal. This reliance not only has adverse health implications but also hinders people's socioeconomic progress. Energy poverty constrains the potential for productivity, educational opportunities, and healthcare services for those residing in rural areas and exacerbates societal disparities.

2.2. Inadequate and Unstable Energy Supply

Approximately one billion individuals, who consume energy at or above European standards, are responsible for approximately half of the world's energy usage. In contrast, nearly 3.5 billion people have limited access to energy and are expected to contribute to less than 10% of total household energy consumption. According to the 2018 IEA World Energy Outlook, about 1 billion people, equivalent to 13% of the global population, currently lack access to electricity, primarily in regions like Africa and South Asia. Sub-Saharan Africa, with approximately 600 million people (accounting for 57% of the population), faces challenges related to electricity access, whereas developing Asia, with 350 million people (9% of the population), also confronts similar issues. Many developing nations grapple with insufficient and unreliable energy supplies. The achievement of universal energy access by 2030 is a key objective among the Sustainable Development Goals established by the United Nations [5]. In various regions, conventional energy sources like coal and natural gas are unable to meet the ever-increasing energy demand, resulting in power shortages, frequent blackouts, and price volatility. These issues have significant repercussions on the normal operation of productive activities and social services.

2.3. Technical, Financial, and Policy Challenges

Do Inadequate energy infrastructure is another impediment to the realization of SD7. In many developing countries, energy transmission and distribution systems are aging and subject to high levels of wear and tear, leading to energy loss and waste. The lack of adequate infrastructure limits the effective integration of renewable and clean energy sources and hinders the promotion and diffusion of sustainable energy. Technological, financial, and policy challenges are also important barriers to achieving SDG 7 in developing countries. Lack of technology transfer, innovation, and knowledge may limit the adoption of clean energy technologies. At the same time, lack of finance and investment, especially in remote areas, makes it difficult to implement sustainable energy projects. In addition, policy incoherence, lack of regulation, and opacity in governance affect the energy sector.

2.4. Responsibilities of Governments and Society

Overcoming these barriers requires the concerted efforts of Governments, international organizations, businesses, and all sectors of society. Governments need to formulate clear energy policies and regulations, provide financial support and incentives, and encourage the private sector to invest in sustainable energy projects. At the same time, all sectors of society need to enhance energy awareness and participate in the energy planning and decision-making process to promote the spread and development of sustainable energy. In summary, developing countries face multiple barriers and challenges in realizing SDG 7, including energy poverty, supply deficits, infrastructure problems, and technical, financial, and policy constraints. However, these barriers can be overcome by adopting comprehensive strategies and cooperation. The successful case of solar home systems in Bangladesh provides valuable insights into the potential and possibilities of overcoming these barriers.

3. Solar Home Systems in Bangladesh: Implementation and Challenges

3.1. Solar Home Systems in Bangladesh

Bangladesh, a developing country with a substantial population, faces a pressing energy supply issue, especially in its predominantly rural areas where energy poverty is prevalent. The nation grapples with the dual challenge of an energy crisis and the impacts of climate change. Bangladesh's energy situation is precarious due to its heavy reliance on natural gas for primary power generation, and the uncertainty of future gas discoveries poses a significant risk. The acute shortage of electricity and conventional fuels affects every part of the country, leading to economic stagnation.

Geographically, Bangladesh is ideally situated between 88°01' and 92°41' E longitude and 20°34' to 26°38' N latitude, making it highly suitable for efficient utilization of solar energy. The daily solar energy potential varies from 4 to 6.5 kWh/m^2 depending on seasonal and climatic conditions. With an estimated average daily solar radiation, Bangladesh has access to a total solar energy resource of approximately 1018 J. In contrast, the country consumed a total of 28.2 Mtoe, equivalent to about 1.18×1018 J of primary energy in 2014. This means that only about 0.5% of the total solar radiation is harnessed annually in the country. Given this context, utilizing a mere 0.12% of the total solar radiation would be sufficient to meet the nation's annual energy requirements [6]. Renewable energy sources, including solar household systems, hold great promise in reducing dependence on fossil fuels [7]. The Solar Home System (SHS) is a significant opportunity for off-grid communities in Bangladesh to gain access to electricity, thanks to the renewable and sustainable nature of solar energy [6]. Considering this situation, the Government of Bangladesh has taken proactive steps to promote solar home systems as means to address the demand for reliable and affordable energy.

3.2. Objectives and Implementation of the Solar Home System Program

Bangladesh's solar home system program aims to address energy poverty and improve living conditions by providing solar electricity to rural households. The objectives of the program include improving the reliability of energy supply, reducing environmental pollution, promoting socio-economic development, and upgrading the living standards of people living in rural areas. In its implementation, the Government of Bangladesh has taken various measures, including the construction of solar panel systems, installation of solar home systems, and provision of training and support. Through financial support, loans, and subsidies, the Government is encouraging the installation of solar power systems in households, thus enabling more people to have access to clean and reliable energy.

3.3. Results and Benefits

The Bangladesh Solar Home System Program has achieved significant results and benefits. First, the program has effectively improved the reliability of energy supply in rural areas. Instead of relying on unstable conventional energy sources, residents have enjoyed a stable power supply and improved

their quality of life. Secondly, the promotion of solar home systems has helped reduce environmental pollution and greenhouse gas emissions. While the use of conventional energy sources usually leads to air and water pollution, solar energy is a clean source of energy that helps improve environmental quality. In addition, solar home systems contribute to socio-economic development. A stable energy supply promotes industrial and commercial activities in rural areas, creating jobs and enhancing economic vitality. According to the Power Sector Master Plan 2016 Annual Report, the goal is to reach 2,470 MW by 2021 and 3,864 MW by 2041. Solar power is expected to provide 748.3 MW of electricity by the year 2021, making about 40% of all renewable energy. Numerous major and small solar technology initiatives are now running to meet these goals (Table 1) [8].

Table 1. Solar technology initiatives

Technology Name	Number of Units	Capacity (MW)
Solar parks	4	38.4
Rooftop solar except NEM	116	41.766
Net metering rooftop solar	147	16.207
Solar irrigation	1675	42.408
Solar mini-grid	27	5.656
Solar nano-grid	2	0.001
Solar charging stations	14	0.278
Solar drinking water system	70	0.062
Solar powered telecom BTS	1933	8.06
Solar home system	5804422	251.64
Solar street light	201754	10.59

3.4. Financing and Installation

In 2003, the Infrastructure Development Company of Financial Institutions Limited (IDCOL) embarked on its solar energy initiative to install 50,000 Solar Home Systems (SHSs) by 2008. By 2014, this initiative, carried out in collaboration with 47 Partner Organizations (POs) under the Renewable Energy Project, had benefited 13 million individuals, installing approximately 3 million SHSs nationwide. Fast forward to 2017, IDCOL has set an ambitious target of building around 6 million SHSs with a total capacity of 220 MW. This remarkable growth demonstrates their commitment to expanding access to solar energy in Bangladesh. IDCOL provides crucial support to its POs to facilitate the widespread adoption of SHSs. This assistance includes technical expertise, logistical support, promotional efforts, and comprehensive training. For instance, Grameen Shakti, one of IDCOL's innovative partner organizations, has already installed over 1,622,865 SHSs and has plans to install an additional 2 million by 2016. Furthermore, they are involved in the development and production of SHS accessories. The Rural Services Foundation's (RSF) project, in collaboration with IDCOL, had installed 482 units and approximately 566,031 SHSs by December 2015. Notably, various government organizations such as BPDB, LGED, REB, and BCSIR are actively engaged in research efforts aimed at advancing the creation and distribution of SHSs in Bangladesh. IDCOL's solar energy program primarily focuses on distributing SHSs in remote off-grid areas of Bangladesh, thanks to funding from institutions like the World Bank, the Asian Development Bank, the Global Environment Facility (GEF), the German Development Cooperation (GIZ), and the German Technical Cooperation (GTZ). The selection of POs is undertaken by IDCOL's PO Selection Committee (PSC), which then extends low-cost soft grants and loans for SHS implementation. The technical committee is responsible for defining technical requirements, evaluating product suitability, and selecting appropriate equipment. Meanwhile, the operating committee oversees the operational aspects of the program. The selection of clients and installation locations for SHSs is delegated to IDCOL's partner organizations, which also provide consumers with micro-credit options and after-sale services. This holistic approach ensures that the benefits of solar energy are made accessible to even the most remote and underserved areas of Bangladesh [6].

3.5. Government and Community Involvement

The Government of Bangladesh has played a pivotal role in driving the success of the solar home system program. Through a combination of incentive policies, financial backing, and technical guidance, the government has actively promoted the widespread adoption of solar home systems. Moreover, it has fostered an environment conducive to private sector participation, which, in turn, has significantly contributed to the growth of the solar energy industry in the country. Another critical factor in the program's success has been the active involvement of local communities. Through comprehensive training and educational initiatives, community residents have been educated about the benefits of solar home systems. This education has empowered them to actively engage in installing and maintaining these systems. The strong cooperation and support from the community play a pivotal role in ensuring the continued operation and reliability of the solar home systems. The case of solar home systems in Bangladesh serves as a compelling example of what can be achieved through a combination of government policy support, community participation, and technological innovation in overcoming energy-related challenges. This success story brings significant benefits to Bangladesh and offers valuable lessons and inspiration for other developing countries facing similar energy access issues.

3.6. Late Barriers to Solar Home Systems

A standard service life for solar photovoltaic (PV) cells is between 15 and 25 years from the installation date. Solar photovoltaic cells can be recycled but also run the danger of producing hazardous waste. Solar panels will eventually degrade into garbage, particularly electronic waste, which might eventually cause environmental issues [8]. Certain solar cells include toxic substances including lead, selenium, tellurium, and cadmium. Since cadmium compounds may be hazardous to fish and other species and can impact people through the food chain, they are now restricted in many nations [9]. Additionally, PV panels, like other energy sources, emit some greenhouse gases (such as carbon dioxide) at some point in their lifespan. PV panels are created in the PV panel industry using pure silicon metal (Simet). Simet must be created by a straightforward thermal reduction of carbon. Simet is created when quartz interacts at extremely high temperatures with reducing substances including charcoal, coal, wood chips, coke, and furnace graphite electrodes in an electric arc furnace [10]. Photovoltaic cells have the potential to be non-cancerous, carcinogenic, and ecotoxic in freshwater, ocean, natural soils, and agricultural soils depending on the components they contain [11]. It is important to note that the initial PV panels installed in Bangladesh have since been removed, and appropriate disposal of used PV panels is becoming a pressing environmental concern [10].

4. Insights and lessons from Bangladesh's Solar Energy

The case of solar home systems in Bangladesh provides valuable insights for other developing countries. It shows that energy barriers can be overcome and access to affordable, reliable, and modern energy can be facilitated through government policy support, community participation, and technological innovation. A combination of government guidance and private sector input can create a favorable environment for development. The experience of Bangladesh could provide lessons for other developing countries. The Government can formulate relevant policies to encourage private sector investment and participation and promote the diffusion of sustainable energy technologies. At the same time, community education and training should be strengthened to enhance people's awareness and ability to use new energy technologies. Transnational cooperation and experience-sharing can promote sustainable energy development on a global scale.

5. Measures and Strategies

To achieve SDG 7 and overcome the barriers within the energy sector in developing countries, multiple measures and strategies can be effectively adopted. These encompass policy innovation,

advancements in science and technology, financial support, capacity-building and training, and international cooperation. Policy innovation stands out as a crucial driver in promoting sustainable energy development. Governments play a pivotal role by creating incentives, initiating regulatory reforms, and extending support for renewable energy and clean technologies. Reducing tax burdens, offering subsidies, and providing incentives can incentivize both businesses and individuals to invest in sustainable energy solutions. The integration of science, technology, and innovation, along with technology transfer, represents another essential avenue for surmounting energy sector challenges. The introduction of cutting-edge sustainable energy technologies can accelerate improvements in energy systems through technology cooperation and transfer. Simultaneously, investments in research and development foster cost reductions for new energy technologies and enhance overall efficiency. Financial support and investment attraction are pivotal components in achieving SDG 7. Attracting domestic and foreign investment to support the construction and expansion of energy projects can significantly bolster sustainable energy development. Financial institutions can offer loans, financing, and venture capital to support the sustainable energy industry.

The importance of training and capacity-building cannot be overstated in popularizing the energy sector. Governments can invest in training and education to elevate the quality and skillset of professionals, thus promoting the diffusion and application of technology. It is equally crucial for community residents to grasp and engage with new energy technologies, actively participating in the construction and management of energy systems. International cooperation and experience sharing represent effective pathways to expedite energy development. Developing countries can collaborate with international organizations, developed nations, and fellow developing countries to facilitate the sharing of technology, capital, and experiences. Through cross-border cooperation and knowledge exchange, developing nations can glean insights from the successful experiences of others and avoid repeating past mistakes. Considering all these measures and strategies, developing countries should holistically embrace policy innovation, scientific and technological advancements, financial support, capacity-building, and international cooperation in their pursuit of SDG 7. By doing so, they can collectively surmount obstacles and work toward achieving universal access to affordable, reliable, and sustainable modern energy.

6. Conclusion

Achieving affordable, reliable, and sustainable modern energy in developing nations is a profound challenge. This paper highlights the significance of modern energy, and addresses issues such as energy poverty, environmental sustainability, and energy inequality, emphasizing the need for accessible, eco-friendly energy sources. It spotlights the success of solar home systems in Bangladesh, illustrating how sustainable energy eradicates poverty, enhances supply stability, and drives socio-economic growth. Government policies, community engagement, and technological innovation play pivotal roles in this success. However, significant challenges persist, including energy poverty, unreliable supplies, infrastructure deficits, and governance issues. To overcome these hurdles, governments must proactively foster innovation, attract investments, enhance capacity-building, and collaborate globally. In conclusion, achieving affordable and sustainable energy is vital for developing nations' sustainable development. Through policy support, innovation, investment, engagement, and international cooperation, these countries can overcome obstacles and pave the way for accessible and clean energy for all.

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