Applications of Sustainable Business Models for PV Systems in Developing Countries

[1]Dr. Dev Ras Pandey, and [2]Sushree Sasmita Dash

[1,2]*Assistant Professor, Department of CS & IT, Kalinga University, Naya Raipur, Chhattisgarh, India.*

ABSTRACT: The global push to boost the adoption of renewable energy resources and decrease our dependency on fossil fuels for electricity generation has experienced substantial growth. Solar Photovoltaic (PV) panels have now achieved a level of extensive implementation and global economic feasibility. These panels, compact and resilient, require only sunlight exposure to generate electricity. Since their commercial use began in Europe in the 1990s, solar PV power has been electrifying countless households worldwide and providing energy access to numerous remote communities in less developed regions. As a result, the extensive global deployment of solar energy systems strengthens the energy industry and fosters job growth, thereby facilitating substantial progress. This study emphasizes the importance of Photovoltaic (PV) technologies and their contribution to advancing sustainability, particularly in emerging economies. It provides valuable perspectives and examinations of the sustainability of solar energy, covering both ecological and economic facets.Furthermore, it delineates the crucial contribution of PV technologies to sustainable development, as they meet energy needs, create job prospects, and enhance environmental conservation initiatives.

Keywords: Solar energy, Sustainability, PV technologies.

1. INTRODUCTION

The increasing global demand for energy derived from fossil fuels is a significant factor driving the rise in levels of Greenhouse Gas (GHG) emissions and air pollutants. The swift growth of the world's population and its energy requirements, especially in developing countries, has given rise to a wide range of concerns, including issues related to poverty, pollution, health, and environmental challenges. Ensuring access to modern energy sources becomes imperative for stimulating production, generating income, and fostering social development, especially in the most economically disadvantaged regions. Furthermore, it serves as a remedy for addressing the serious health issues arising from the utilization of traditional fuels like fuelwood, charcoal, animal dung, and agricultural waste. Solar energy emerges as a feasible solution for alleviating energy poverty and holds substantial potential

[1]ku.devraspandey@kalingauniversity.ac.in
[2]ku.sushreesasmitadash@kalingauniversity.ac.in

for reducing greenhouse gas (GHG) emissions and indoor air pollution. More specifically, solar photovoltaic (PV) technology has proven its suitability as a source of renewable electricity in developing nations, particularly in remote rural areas where extending the electrical grid is either economically or technically unfeasible [1]. PV systems can also contribute to diminishing the demand for fossil fuels and the associated emissions, encompassing carbon dioxide (CO_2), nitrogen oxides (NOx), and sulfur dioxide (SO_2). Estimates indicate that by 2030, the adoption of PV systems could lead to emissions reductions of approximately 69–100 million tons of CO_2, 126,000–184,000 tons of SO_2, and 68,000–99,000 tons of NOx.

In response to increasing energy demands, the global solar energy capacity has expanded at a remarkable pace. Between 2010 and 2020, photovoltaic (PV) technology experienced substantial growth in installed capacity, increasing from 40,334 MW to 709,674 MW. Simultaneously, during the same period, Concentrated Solar Power (CSP) applications also saw expansion, rising from 1,266 MW in 2010 to 6,479 MW by the end of the decade. Consequently, solar PV technology now boasts a higher number of deployed installations compared to CSP applications. This, in turn, has driven the widespread adoption of standalone solar PV systems and large-scale grid-connected PV plants worldwide, including their utilization in space applications [2].

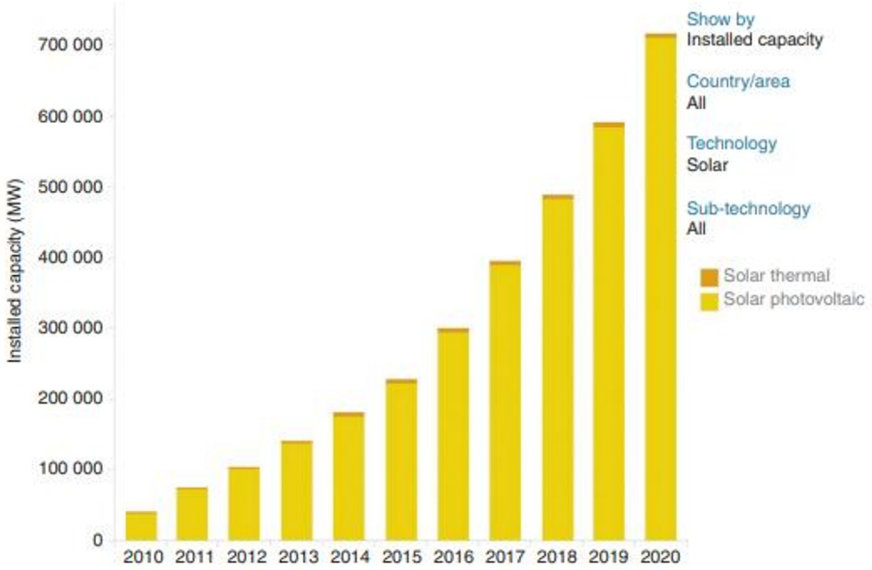

Figure 1: Installation rates of solar energy worldwide.

Rapid developments in technology and cost reduction have made PV systems (and therefore electricity) more accessible in places where this was previously not possible. Non-electrified communities in developing nations perhaps value this change the most. While small PV based products (sub 10W) have been popularly commercialized recently, owning large PV systems (several 100W) is still an elusive dream for people with limited buying power. Therefore, a solution would be explored through this project that integrates PV, storage and delivers DC/AC output for powering appliances in a way that enables people to use electricity affordably.PV technology can be proven as the most reliable alternative to conventional energy sources but, indeed, the efficiency of the same is not at a satisfactory level till now. Moreover, the requirement of high capital initially to install the system is also one of the major hindrances in the diffusion of the same [4]. Therefore, it is an important research area which needs significant attention and contribution. To begin with, it is crucial to pinpoint the challenges associated with the adoption of solar energy and

eliminate the obstacles. Moreover, a sustainable model of the application of PV systems for developing countries is essential. Through the literature survey, it was realized that not much work exists in the application area of PV systems. Therefore, the objective is oriented towards a sustainable model of the application of PV systems for developing countries and an understanding of issues and challenges of green energy in developing nations. Keeping this view, the objectives of the study are as follows:

1. Investigation of various issues and challenges in the implementation of Photovoltaic systems as a green energy solution in developing nations.
2. Modelling of Photovoltaic systems used as a green energy solution for developing countries.

The remaining sections of the paper are structured as follows: Section 1 introduces PV systems, Section 2 delves into the foundational aspects and related research, Section 3 provides an overview of PV systems, Section 4 explores the rules governing their presentation, and Section 5gives the conclusions and follow-up work.

2. RELATED WORKS

Boons et al. [5] underscore the importance of business models, asserting that they should be recognized as essential elements within socio-technical systems. To foster greater market acceptance of renewable energy technologies, it becomes imperative to enhance infrastructure, implement regulations more attuned to customer needs, and provide support mechanisms, as these factors directly impact the viability of a business model. Similar to how niche experimentation aims to empower a specific niche to compete with established technologies in the market, experimenting with the business model serves a comparable purpose. Transition theories underscore the crucial significance of entrepreneurial endeavours in instigating transformation and facilitating the diffusion of novel ideas. As posited by Koubaa [6], entrepreneurial enterprises in less developed countries confront a multitude of hindrances, including restricted access to financial resources, insufficient protective measures for investors, governmental regulations, political volatility, and a dearth of information to foster innovative business concepts. These hurdles substantially impede an entrepreneur's capacity to capitalize on prospects. Consequently, in the absence of exploration and education intertwined with a business framework, numerous market openings may go unexplored.

Bidmon and Knab [7] contend that business models are pivotal in enabling communication among diverse stakeholders, serving as vital conduits for articulating visions and anticipations concerning specific technologies. This, in turn, enables the clarification of how value is created and the methods for capturing value connected to technology within the innovation ecosystem's participants. While business models might not have a primary role in forming social networks, they do contribute to improving communication among a wide range of actors within innovation networks. This, in turn, supports the processes of learning and the formation of social networks, ultimately capturing the attention of consumers and investors.

Furthermore, the role of business models in promoting learning processes within organizations is significant. They function as central hubs of knowledge, thereby establishing a competitive edge for emerging technologies and drawing in fresh participants to the network. Consequently, when an innovative business model is integrated with technology, it enhances the likelihood of wider stakeholder adoption, facilitating its proliferation across various markets. Bidmon and Knab [8-9] emphasize that enhancements made at the business model level can initiate changes within technological niches, ultimately influencing the adoption of particular technological designs. This highlights the significance of stakeholders avoiding excessive reliance on established business model

paradigms, such as a strong dependence on donor funding for companies in numerous developing nations, and instead creating opportunities for innovative business models to emerge.

3. OVERVIEW OF PHOTOVOLTAIC SYSTEMS

PVC is the basic building unit of PVAs (Photo Voltaic Arrays) in PVC systems. PVC is made from semiconductor devices like silicon, germanium etc. The semiconductor components are thin slices/wafers with holes and work on the principle of potential differences in electrons. These changes in potential differences across wafers produce a certain amount of voltage and generate electricity when the wafers are connected to an electrical circuit. The movement of electrons creates a current flow in the system [10].To simplify the analysis, we have created a moderately complex mathematical model. This corresponding model is depicted in Figure 2 and comprises a current source and a diode connected in parallel with it. These components jointly define the V-I characteristics of the cell. It's important to note that the current source's output is directly linked to the intensity of solar radiation incident on the cell.

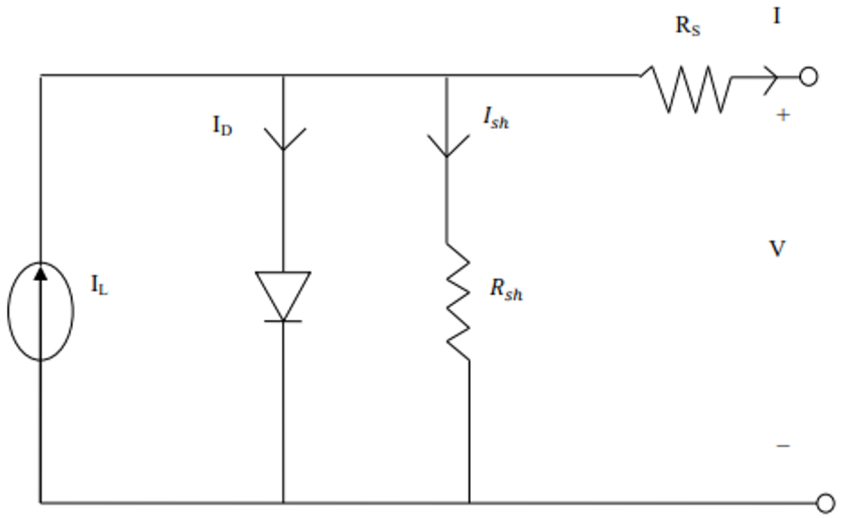

Figure 2: Equivalent circuit of PV module

A series resistance (R_s) is integrated to enhance the accuracy of the curve between the maximum power point and the open circuit voltage. Additionally, a shunt resistance (R_{sh}) is connected in parallel with the diode to achieve matching characteristics. This configuration dictates the output current of the solar cell.

$$I_0 = I_L - (I_d + I_{sh}) \quad (1)$$

Where

$$I_d = I_0\left(exp\left[\frac{q(V_o+R_{se}I_0)}{KT_k}\right]-1\right) \quad (2)$$

$$I_{sh} = {(V_0 + I_0R_{se})}/{R_{sh}} \quad (3)$$

$$\text{i.e.,} I_0 = I_L - I_0\left(exp\left[\frac{q(V_o + R_{se}I_0)}{KT_k}\right]-1\right) - {(V_0 + I_0R_{se})}/{R_{sh}} \quad (4)$$

Where V_o= output voltage (V)

I_o= output current of the PV (A)

R_{se}= series resistance of the solar cell (Ω)

R_{sh}= shunt resistance of the cell (Ω)
q = electron charge (1.6×10^{-19})
I_L= Light generated current from PV cell (A)
I_d= diode saturation current (A)
K= Boltzmann constant ( )
T_k= Cell temperature (K)
The values listed in the equations above were derived based on the evaluations of the solar PV array.
PV system has emerged as one of the major power sources by gradually turning into more affordable and reliable than conventional utilities. It promises more brighter and cleaner future for the future generations. Some of the benefits of implementing PV systems are listed as follows:

- PV systems convert sunlight into electricity directly. PV devices are rugged in construction and simple in design. Moreover, the maintenance required by PV devices is very low.
- One of the great advantages of PV systems is the capability of utilizing them as standalone systems which can provide output over a wide range i.e. from microwatts to megawatts.
- Solar power produced by PV systems lowers our electricity bills and insulates us from utility rate hikes. Installation of PV systems has proven to be beneficial by giving rise to property value and home resale opportunities.
- PV modules have no moving parts and their operation is completely silent, consequently, they act as a perfect solution for urban areas and residential applications.
- The cost of solar panels is gradually decreasing and certainly continues to reduce due to advancements in technology. Therefore, solar PV panels promise a bright, economically viable and sustainable future.
- Installation of residential solar panels on rooftops or ground can be easily done without creating any interference to urban lifestyle.
- PV systems offer a wide variety of applications in diverse sectors such as water pumps for agriculture, reverse osmosis plants, smart homes having rooftop solar systems, digital-era communication devices, satellite and space vehicles, and large-scale power plants.

3.1. Business model and Projects in developing countries

Business models for portable solar products exhibit notable variations, particularly in the case of products like WakaWaka. For instance, WakaWaka is available for purchase in Europe, and for every product sold in Europe, one is provided to someone in the developing world through sponsorship. On the other hand, SolarWorks offers its products directly to customers or even to non-governmental organizations (NGOs), enabling the distribution of products to rural areas. Both WakaWaka and SolarWorks have established themselves in the market as successful enterprises. However, SolarWorks exclusively concentrates on the developing world, while WakaWaka markets its products to customers in both developed and developing countries. The key distinction lies in the fact that in the developed world, WakaWaka products are available for purchase through an online store, whereas in the developing world, each product sold in Europe sponsors a product for those in need [11].
The UN World Summit on Sustainable Development, convened in Johannesburg, South Africa, aimed to promote greater collaboration among governments, corporations, non-governmental organizations, and a wide array of stakeholders. Its primary objectives included the elimination of poverty and the promotion of greater equality in the distribution of globalization's benefits. Solar Energy International (SEI) serves as an illustration of an organization actively involved in advancing these goals. SEI partners with community-

based development organizations at the grassroots level to advance sustainability through the adoption of renewable energy resources. Additionally, SEI provides education and training for individuals involved in these technologies and actively participates in the planning and execution of sustainable projects. SEI also extends support to volunteering programs.

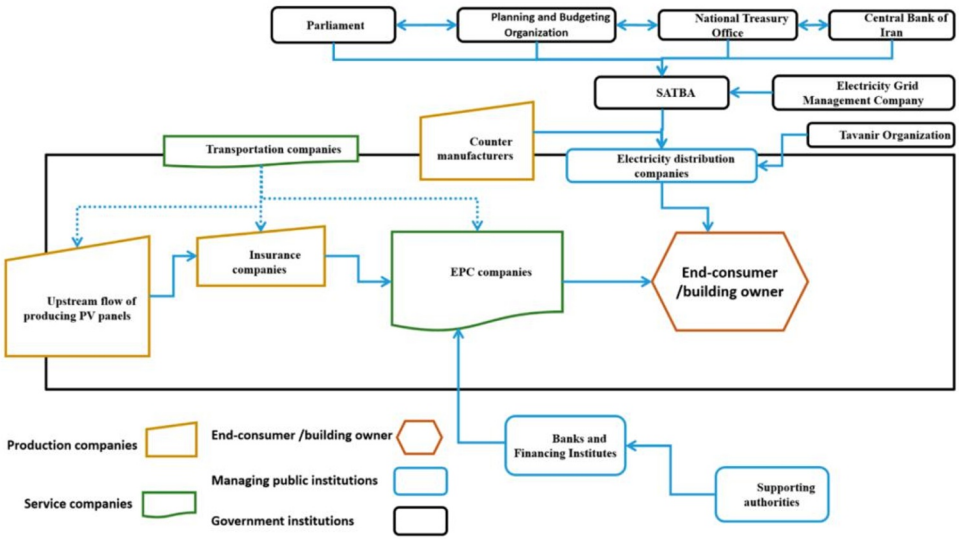

Figure 3: Sustainable business model

This group of skilled professionals brings together their extensive knowledge covering diverse geographic areas, including the Americas, Africa, Micronesia, and the Caribbean. They have shared their expertise with a broad spectrum of recipients, such as the Pan American Health Organizations, Non-Governmental Organizations (NGOs), foreign and domestic governments at various levels, universities, and individuals interested in harnessing the advantages of renewable energy. They are but one of the numerous organizations actively participating in numerous initiatives dedicated to advancing sustainability in emerging economies. Solar Energy International has established its organization intending to improve living conditions for people, and it strives to set high standards of excellence in this field as it works towards achieving its mission.

The primary appeal of international funding for solar energy in developing countries lies in its capacity to advance clean energy sources and enhance fundamental living conditions. Funding opportunities for developing nations are accessible through a variety of channels. Many international and bilateral aid organizations offer financial assistance for development initiatives, with a particular emphasis on bolstering solar projects, thereby fostering the expansion of the market. Major projects of tens of $M have installed PV systems in remote villages in countries such as Indonesia and the Philippines. An increasing trend is the funding of sustainable, locally-based enterprises that can affordably provide PV systems through micro-finance, for example using revolving funds. Solar power is increasingly finding use in projects focused on enhancing education, water supply, and healthcare in these areas. While the significant upfront costs of installing photovoltaic systems are recognized, despite their long-term cost efficiency, there is a growing focus on utilizing microfinance to enhance their accessibility. Kenya stands out as a prominent developing nation with a robust unsubsidized market, offering low-power (10-20W) "entry-level" modules to its customers [12].

The role of PV in sustainable development

Sustainable energy development involves the creation of energy systems that are in line with sustainability principles throughout their lifecycle, including energy generation, distribution, and utilization. These energy systems have a significant impact on the environment, affecting both developed and developing countries. As a result, a global framework for sustainable energy should prioritize improvements in efficiency and the reduction of emissions[18]. The core idea of sustainable development focuses on economic aspects, evaluating actions needed to achieve common long-term goals related to preserving the climate, ensuring clean air, and promoting equitable access to energy. Immediate strategies are derived from the International Energy Agency's Sustainable Recovery Plan, which aims to stimulate economic growth and job creation by building cleaner and more reliable energy infrastructure. Sustainable development is marked by the incorporation of renewable energy technologies, intelligent grid solutions, initiatives to bolster energy security, and a well-crafted energy pricing strategy, all underpinned by a robust energy policy framework [13]. Demand-side response strategies serve a crucial role in meeting the flexibility demands of electricity systems by adapting demand patterns over time. This approach curtails the reliance on renewable technologies for handling peak demand, ensures system stability, and leads to overarching cost and CO2 emissions reductions. Currently, demand-side response strategies are mainly implemented in Europe and North America, with a primary focus on large commercial and industrial electricity consumers.

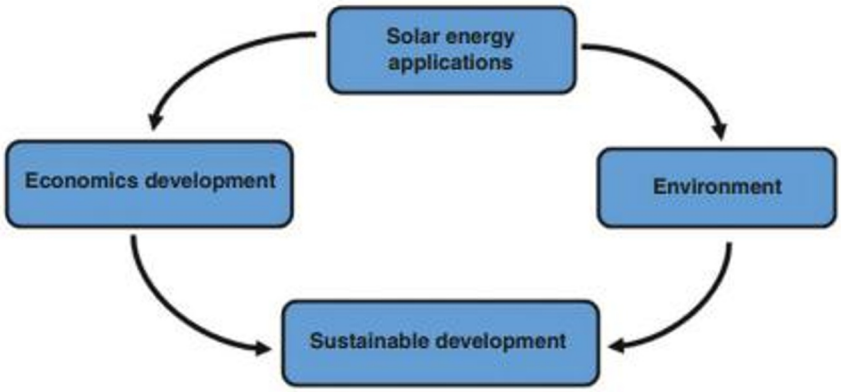

Figure 4: Framework for solar energy applications in energy sustainability

The ongoing expansion of solar Photovoltaic (PV) and other renewable technologies through trade will enhance the country's infrastructure[16-17]. For instance, off-grid solar energy solutions like standalone systems and mini-grids can be readily employed to bolster healthcare facilities, thereby enhancing their service capacity and supplying power to mobile testing sites and vaccine storage facilities. Beyond immediate assistance in dealing with healthcare crises, the adoption of solar PV enabled by trade can play a pivotal role in the economic recovery post-COVID-19 pandemic. This includes creating employment opportunities within the renewable energy sector, which is projected to surpass 40 million jobs by 2050. The framework for advancing energy sustainability, with a particular emphasis on solar energy applications, provides a practical pathway to achieving these objectives. Given the abundant availability of solar energy resources for both PV and Concentrated Solar Power (CSP) applications, we can make substantial strides towards achieving energy sustainability [14-15].

Table 1: List of the top 10 countries that created jobs in solar PV applications

Continent	Country	Prevalent jobs (millions of jobs)

Asia	China	2.240
Asia	Japan	0.250
North America	United States	0.240
Asia	India	0.205
Asia	Bangladesh	0.145
Asia	Viet Nam	0.055
Asia	Malaysia	0.050
South America	Brazi	0.040
Europe	Germany	0.030
Asia	Philippines	0.020

4. DISCUSSIONS

Securing dependable and sustainable modern energy services is a pivotal aspect of advancing development. Among the pressing environmental issues linked to producing and using energy is the discharge of greenhouse gases and their harmful consequences. The considerable capacity of renewable energy sources to fulfil upcoming energy demands while not exacerbating greenhouse gas emissions has urged countries to investigate the contribution of renewables in fulfilling their energy needs. Photovoltaic (PV) technologies exhibit great potential in tackling energy scarcity issues amidst a continually expanding global population and the goal of enhancing living standards. PV systems generate electricity without producing air pollutants, offering substantial environmental advantages compared to conventional energy sources. They contribute to the reduction of CO2 emissions and other harmful substances, help mitigate global temperature rises, and serve as a practical model for sustainable energy strategies.

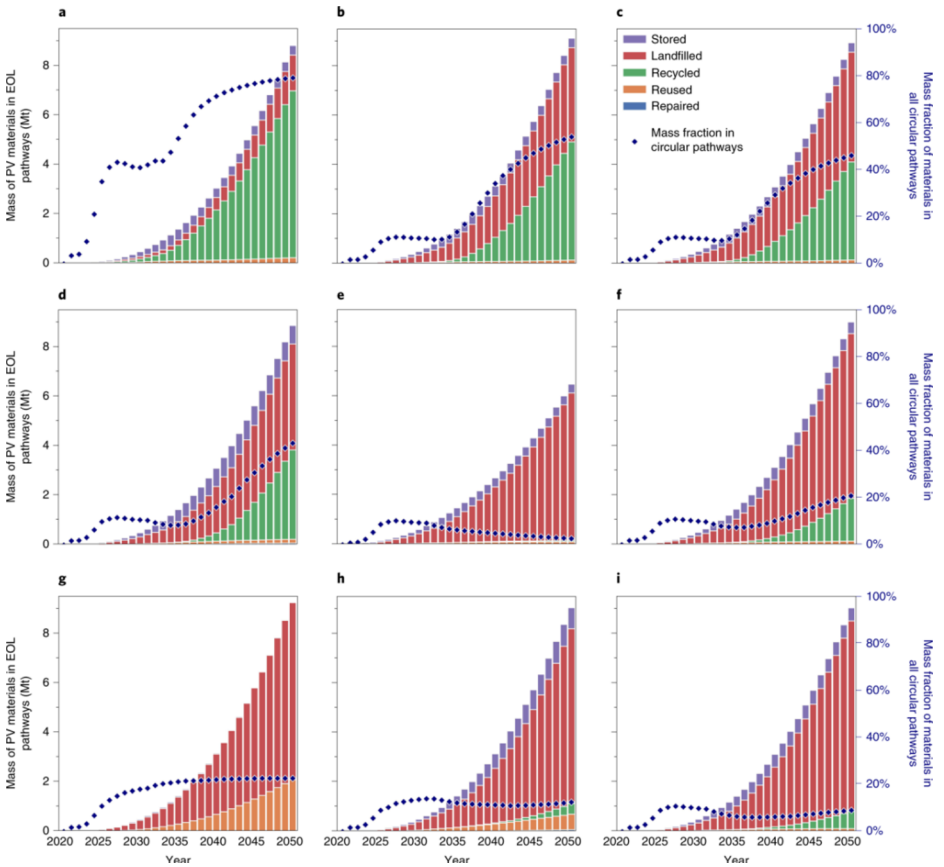

Figure 5: Uses of PV in developing countries

As a sustainable and renewable resource, solar energy holds great promise in contributing to a secure and dependable energy future by fostering diversification. Out of the diverse uses of solar energy technologies depicted in Figure 5, solar electric power systems and solar cookers stand out as clear and exceptionally beneficial applications. For instance, photovoltaic-powered home appliances provide improved kitchen conditions, particularly benefiting rural women in developing nations, offering a healthier alternative that can enhance their overall quality of life. In regions where it's not economically or technically viable to extend the electric grid, off-grid solar solutions offer a swift and adaptable option that often becomes the most practical choice for providing electricity. Despite the various benefits of solar energy for the environment, economy, and society at large, several obstacles hinder its widespread adoption. One of the primary challenges lies in the initial expense associated with solar panels. To accelerate and streamline the expansion of solar energy, governments in developing nations should establish a comprehensive suite of policies geared towards encouraging the adoption of solar energy while diminishing reliance on fossil fuels and biomass resources. These policies may encompass legislation, regulations, economic incentives, tax advantages, and investments in technical research and development. Furthermore, phasing out or reducing inefficient fossil fuel subsidies and implementing robust support programs can render investments in solar energy financially appealing.

5. CONCLUSIONS

Sustainability stands as one of the most precious legacies we can bequeath to the generations that follow. As solar energy becomes more affordable in comparison to other renewable energy options, it holds the promise of improving the well-being and economic opportunities of numerous marginalized communities in developing countries. The potential of solar power extends to both active utilization, such as the use of solar PV panels, and passive integration through eco-friendly architectural designs. These approaches have the potential to bring hope and opportunity to the most remote and underserved regions of our planet. With innovative engineering, this technology can also extend its reach into the transportation sector. This paper underscores the critical importance of sustainable business development in the context of Photovoltaic (PV) technology within developing countries. Solar energy has the capacity to stabilize energy prices while delivering a plethora of social, environmental, and economic advantages. The contributions of solar energy toward achieving sustainability are manifest in its ability to meet energy demands, foster job creation, and safeguard the environment. As PV technology continues to evolve, there has been a notable increase in global demand for its applications. It is imperative that ongoing efforts are directed toward the sustainable development of energy and the exploration of alternative clean energy resources. Furthermore, the meticulous execution of comprehensive experimentation and validation processes for these applications is vital to the realization of cleaner energy sources, essential in our collective pursuit to decarbonize our planet.

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