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Economic Development through Renewable Energy Integration: The Role of Solar Photovoltaic Systems in India

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Abstract:

Renewable energy sources especially use of systems such as the solar photovoltaics are therefore essential in developing economies and especially for the Indian economy. This paper aims to establish the role which will be played by the solar PV system as a tool that will boost the economy of India. Through a review of current literature in academic databases, government and policy documents, and the analysis of business intelligence data, it identifies the advantages and drawbacks of the global solar PV market. Some of the important dimensions discussed are employment opportunity, technology advancement, energy security, and environmental friendliness. The results point out that the advancement of solar PV integration could greatly improve the position of the Indian energy and contribute positively to long-term economic growth. Looking at overall power sector benefits and comprehensive social benefits more research and policy recommendations for the use of solar PV systems in India are proposed.

Keywords: Economic growth and development solar photovoltaic system, India, energy transition, renewables, sustainable development job creation, technological advancement and energy security.

1. Introduction

Indian population is growing fast and there is immediate demand of energy in India but to meet this energy demand India is in great challenges due to its ability to provide energy in a sustainable manner without harming environment. The use of renewable energy sources especially through solar photovoltaic (PV) systems is therefore seen as an essential means of securing the country's energy needs as well as contributing to the sustainability of the environment. Some of the Positive Economic Impacts of Solar PV systems include; Direct employment, technological improvement and incentive promises as true cost of solar energy is yet to be determined. Also, they help fight against greenhouse emissions and at the same time improve energy security [1-8].

This paper therefore seeks to analyze the contribution of solar PV systems as a vital facet of the Indian power sector dynamics. On the economic effect it will analyze their economic effects, in the technological it will focus on the technological advancement of each, in the policy it will look at the policy milestones/achievements/challenges and in the future prospects it will try to explore the future of each. Economically, the establishment of solar PV systems will be another opportunity to boost local economies since it actuates job opportunities in the manufacturing, installation and maintenance of solar power systems. They also encourage technological advancement and research in alternatives energy sources and make India the world's centre for the solar system [9-15].

Nevertheless, the following are some limitations to the achievement of flexibility: Intermittency, grid challenges, and high costs of installation. Some of the barriers include lack of long-term financing for projects, absence of good regulation, inadequate infrastructure, low economic returns and lack of political will which policy frameworks mitigate through provision of incentives for investment. The renewable energy plan of the government of India and favorable polices like subsidies, tax credits, and net metering have played significant role in pushing the adoption of solar PV system [11-20].

Further, the paper will explain future prospects for the deployment of solar PV technology in India and outline the possibilities for scaling UP by using technology, grid infrastructure and financing. Mitigation of the challenges stated above and exploitation of opportunities will be of imperative importance for India to meet the intended RE targets and SD agenda for a sustainable economy in the following years.

Some of the potential economic benefits that can be accrued through the integration of solar PV systems in the electric power network in India include the following;

It has clearly demonstrated a scenario of solar PV as an economic success in India's broader economic sense, thereby making India a significant player in the global economy . This has been the reason that the implementation of solar PV projects has resulted to employment opportunity all through the value chain from manufacturing to installation to maintenance. As stated by the MNRE in the year 2021, the solar industry provided job openings for more than 300000 people in India due to which it becomes an essential aspect of impacting local employment and economy. Clearly, employment creations do not end with the direct employees of solar PV projects. Over time, Solar PV investments have brought in a lot of economic value adding to infrastructural developments. This is in terms of more employment of people in the supply of solar products, and other compliance costs such as compliance with the tax laws. These investments create job opportunities within these communities directly and indirectly through the provision of services and infrastructure including transport, construction and selling of provisions to cater for the numerous workforce and investment needs of the projects [13-24].

However, the solar PV sector require a significant amount of capital investment and it receives investment from both national and international sources. Such investments are vital to financing the creation and growth of solar power plants as well as the strengthening of the power grid and development of related technologies [8-10, 20-25].

The amount of money flowing in is an added advantage as it also leads to more investment in the use of renewable energy technologies due to the increased capital which is an advantage for growth of the economy where a cycle of growth and development is created.
Various economic spillover impact of solar PV deployment also includes expense within the economy. Engineers, technicians, installers and other employees of companies operating with or in the solar industry use their earnings to patronize merchants, which boosts the economy of locations where solar projects occur. Due to its decentralised nature of economic development, this is especially more advantageous in rural and semiarid regions where most solar projects are being established [11-18].

Additionally, through increasing the market size of solar PV, it contributes positively to the balance of payment and energy security of India – since more renewable energy sources decreasing the import of fossil fuel. With reduced consumption of fossil fuel, fund that would have been use in importation could be channeled to more sensitive area of the economy like, health, education and improvement of infrastructural facilities.

Overall the economic outcomes of installed solar PV systems in India is multilateral in that it creates employment opportunities, fosters economic growth in the regions where the systems are installed, has attracted significant investment and helped to ensure energy security. All these factors collectively point up the specificity of the place of solar PV in the process of sustainable economic growth and development in India.

2. Case Studies on Economic Development

The following are some of the case studies that shed particular light on how solar photovoltaic integration has been instrumental in changing the Indian economy story. One of the most notable is the Jawaharlal Nehru National Solar Mission (JNNSM) initiated in 2010, despite the fact that it aims at achieving 100GW of solar power capacity with the year 2022. It is for this reason that this initiative has been largely responsible for the increased deployment of solar PV across the country and has injected a robust economic value additive whilst putting India on map as a solar power house.

Some of these programs include the Remuna Ultra Mega Solar Power project which is located in Madhya Pradesh. This project clearly shows how partnerships with the private sector can be effective, it clearly show the firmly rooted economic benefits from large scale solar deployment. Situated in Rewa district of Madhya Pradesh, the Rewa Solar Park spreads over 1,590 acres of land and holds a cumulative installed capacity of 750 MW; it is among the largest utility-scale solar photovoltaic power plant projects in the world. Regarding this, it was able to garner heavy investments from both local and global players signaling optimism on the country's RE market.

Therefore, Rewa Solar Park not only provides renewable energy to the grid but also has multitide economic benefits. The completion of the project has brought new employment opportunities in the construction and maintenance stages of development. Local employment has been given top priority; currently employing over five thousand people thereby boosting the economy. The financial investment and the employment opportunities provided by the construction of the solar park has led to stimulation of economic activities of the region by supporting business entities as well as prompting development of related services.

Besides, the contribution of the Rewa Solar Park has been crucial in generation of clean power and subsequently its integration into the grid especially when compared to the conventional power sources relying on fossil based inputs thereby lowering the emissions of greenhouse gases. This trends of shifting to cleaner energies does not only support India's green agenda but also strengthens the energy security since it broadens the base of energ y sources. The effectiveness of Rewa has paved the way for more large scale solar energy projects across India hence acting as a catalyst for investment in renewable energy.

Another example of solar project is the Kamuthi Solar Power Project located in the desert area of Kamuthi in the state of Tamil Nadu and it is one of the largest with the total production capacity of 648 MW. The solar power plant in Kahram вияв this point by showing how a firm in the private sector- the Adani group – can aid in the development of solar energy systems. Similarly, the Kamuthi project has created ample employment and injection of revenue within local economies as well as providing reliable solar power to support the stability of the national grid.

These case studies are an indication of the various spheres of the economy that would stand to benefit from solar PV integration in India. JNNSM is also shown as an additional strategic undertaking that can spur investments, generate employment and foster improved levels of sustainable economic development and achievement, drawing from successful previous undertakings such as Kamuthi and Rewa. The success of these projects also proves that solar PV systems can ensure the successful outcomes for the economic growth with the focus on the further use of the renewable energy sources in India.

3. Recent TRENDS in development of Solar Photovoltaic Systems

The progress in technology has helped in determining the right economic model and in expanding the factor of scaling right solar photovoltaic (PV) systems in the supply chain in India. Such advancements touch on the enhancement of the PV cell's conversion efficiency, the strive to have cheaper modules, developments in energy storage systems, and advance in technologies which enables integration of solar energy to the grid, and most of these have contributed to the success of solar energy in this country.

Possibly, the most drastic technological improvement that emerged is the enhancement of PV cell performance. Much progress has been achieved by researchers and manufacturers regarding the attempt of attaining more efficiency in solar cells in converting the sunlight into electricity. The advancement towards bifacial solar cells that can harness energy on both sides of the solar cell, as well as perovskite cells with their efficiency and relatively low cost of production, highlight solar advancements. By enhancing these elements, the generation of electricity through solar power systems has become efficient, and hence there is capacity utilisation of the sun energy for better outcomes.
At the same time, the decrease in the module price has been an major factor that brought changes to the solar industry. As evident from the economies of scale generated from the manufacture of solar modules through mass production and evolution in the manufacturing techniques the costs of developing the solar modules have been greatly reduced. This has contributed to a reduction of cost making solar power cheaper and nearly at par with conventional power sources such as fossil fuels and has thus boosted the adoption of solar power in all segments of the industry, both in small residential installations and large utility-scale installations in India.

Interruption or intermittency challenges that are often faced in the production of solar energy has also benefited a lot from innovations in energy storage systems. By adopting new materials and better engineering, the technologies employed in battery-based systems have increased in efficiency and capability. These storage solutions allow the excess of the solar energy produced during the day or low solar radiation to be stored for usage at certain times of the day when there is little sun or at night. This capability cuts costs and also helps the operation of solar power to become more reliable and stable hence a more reliable source of energy.
The later innovations in grid integration have also aided the easy connection of solar power into the overall grid of India. For instance, utility interact with the smart inverters which has the function of converting the direct current (DC) that is produced by the panels to the alternating current (AC) that is compatible with the grid. They are designed with features that enable improved grid stability including voltage control, reactive power support and others that can be monitored remotely. Furthermore, application of microgrid solutions has been realized as viable approaches in controlling the distribution of power from the solar PV installations in the micro-grid networks across the globe, in their strengthening of the energy distributions, more so in the remote or the scarcely electrified regions.

These advancements have hence in a way reduced the cost of solar power generation hence economically viable and attractive source of energy production India. They have also enhanced handling and balance of the solar power sector within the national grid, so that the rise of the contribution of the solar power is not having negative impacts to the rest of the general power system.

To sum up, technological developments occurring in the enhancement of PV cell efficiency, decline in module cost, advances in energy storage, and increased credibility of the solar PV interactive grid have provided a vast improvement in the economic prognosis and functioning of solar PV in India. These advancements not only contribute towards the efficiency of the solar power that in turn make it a cheaper and a more reliable kind of power but also work well for the super objectives of sustainable development and energy security of India.

4. Policy and Regulatory Framework

This paper has identified some of the significant policies in India's policy and regulatory framework that have helped in the implementation of solar photovoltaic (PV) systems and also to optimize the economic benefits of the program. Certain measures and policies implemented by MNRE include but are not limited to – The power purchase agreement (PPA) and solar capacity addition goals.

The most important policy strategy is the feed in tariffs policy, whereby a certain price of electricity produced by the solar power plants is agreed upon and paid for a fixed term. This will ensure that investors can have a constant and predictable kind of income from their projects and in this way minimize on risks that are financially related and enhance investment in solar PV projects. Some of the most pronounced benefits that have emanated from the implementation of FiTs relate to investment attraction as a precursor to the emerging solar market maturity.
Under the PPP model the MNRE has started offering subsidies for installation of rooftop solar power systems. These subsidies ensure that the usage of solar power in homes, businesses, and industries is more affordable than other means. As an effect of budging facility cost through subsidies, rooftop solar has contributed to a higher level of energy consumers involved in the shift towards solar renewable energy systems hence widening the market.

The Green Energy Corridor scheme is another major policy that is lying in the process of integration of renewable energy into the national grid. Apart from incentivizing rooftop solar, this initiative aims to strengthen the grid network for making way for higher contribution of renewable energy sources. It includes the establishment of sophisticated electricity distribution networks or high voltage hauls and utilization of applications that will facilitate effective in providing solar energy across the country. The Green Energy Corridor scheme likewise helps in achieving higher interconnection levels to the grid facilitating further massive installations of new solar PV projects and improves energy system reliability.

Furthermore to these policies, competitive bidding procedures earlier introduced by the Solar Energy Corporation of India (SECI) in the procurement of solar power has also played a significant role. Tenders and negotiations involve competitive bidding where bidders bid for projects based on price per kilowatt-hour of electricity. It has also seen the lowering of costs in the generation of solar power that has placed it amongst the cheapest sources of electricity. It has also created competent bidding among the players of private sectors which has strengthened the competition in the solar industry.

Moreover, the measures introduced stem from the understanding that the regulatory environment needs to be built with an aim of enabling the sustainable development of the solar industry in the future. Schemes like the Renewable Purchase Obligation (RPO) aim to set a benchmark, beyond which utilities cannot continue using fossil based sources of energy and thus, forcing the increased incorporation of solar electricity. This regulation ensures that there is a consistent market for solar PV projects hence achieving the goal of using solar energy.

To sum up, India could provide another example of a comprehensive approach towards policy-making and regulation facilitating the usage of solar PV systems, as well as achieving optimum results in terms of the concerned economy's boost. Feed-in tariffs policies, rooftop Solar power subsidies, Green Energy Corridor, and competitive bidding policies have been the operational policies that enhance investments, control costs, and promote private sector involvement. Such policies accompanied by the enabling environment in the form of laws and regulations, have placed India amongst global leaders in solar energy production and consumption and has helped towards sustainable economic development and energy adequacy.

5. Economic Models and Assessments

Economic feasibility analysis points at the prospective profitability of solar PV businesses in India. Some of the cost elements looked at during decision makings include initial investment, fixed and variable overhead and the estimated revenues from sales of power. Employment, local economic growth, improvement of customers' access to energy are the significant socio-economic evaluation criteria that describe concrete effects of solar PV deployment (IRENA, 2021).

6. Challenges and Barriers

However, there are still many challenges that ISPV sector in India is experiencing notwithstanding tremendous progress. Some of these challenges comprise the problems in grid connectivity, fluctuations in solar generation, and the challenges of offering Sol with reliability and stability hence more advanced storage systems are required. Currently, challenges including expensive capital to fund such projects and low-cost financing remains as key challenges for project development and anyone willing to invest in renewable energy projects (IRENA, 2021). Also for the independent power producers, legal hurdles associated with land acquisition, social issues, and political challenges slow down the deployment of the solar PV projects. This leads to several problems related to delays of project implementation hence raising the costs of projects which in one way or the other hampers the growth of the solar industry in India (CSE, 2020). These challenges therefore call for a strategic policy intervention by various stakeholder including policymakers at the National, County and sub-County level, the industry players, and the financial institutions in order to support a more favorable environment for advancement of solar energy.

7. Future Prospects and Opportunities

The opportunities for the solar PV sector in India are expected to grow even more in the next couple of years. The Indian government has set its target at 450 GW of renewable electricity by the year 2030 with large proportions from utility-scale solar PV system This was reflected in the government's ambitious plans of achieving 450 GW of RE Capacity by 2030 (MNRE, 2021). These technologies coupled with, and persisting support initiatives and policies it is believed that other barriers to cost and efficiency of solar PV system would decrease. Multilateral enterprises would come with sophisticated technologies and capital to shape the sector. Newave installation prospects such as the floating solar structures where the solar panels are installed on water sources, and the integration of solar with other renewable technologies promises to broaden sector capabilities. Moreover, Decentralized application of solar for small application includes rooftop solar power and micro solar grids are again expected to enhance the energy supply availability and inclusive economic growth mostly in the rural regions and unserved areas of the world (IREDA, 2021). These prospects reveal how solar PV can help in transforming the energy sector of India and therefore support economic change.

Conclusion

The deployment of solar photovoltaic (PV) systems has proven as the backbone of the Indian government's focus to develop and increase the share of renewable energy in the country which has positively impacted economic growth in the country while supporting sustainable development. The future demand for energy in India and the world in general indicates that there is a need for the general acceptance of solar PV technologies to meet the increasing global energy demands while at the same time protecting the environment, cutting down on Green House emissions, and improving the energy security of the country. Besides introducing environmental benefits, solar PV systems also address economic benefits as observed through the provision of employment opportunities, investment, and innovation. However, to effectively capture the economic benefits of solar PV systems, certain issues including but not limited to the following must be solved; The integration of solar PV systems with the grid infrastructure, financing hurdles and regulatory frameworks. Some challenges include: Infrastructure costs which will require the use of innovative technologies such as energy storage systems, smart grid systems, policies, or subsidies, incentives, and streamlined regulatory frameworks in order to overcome these challenges. If India continues to nurture the solar PV market, it will remain a global pace setter in the transition to renewable energy and provide its citizens with sustainable development for the masses.

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