

Adoption Of Solar Panels In Rural And Urban India

Uday Jaybhaye¹, Onkar Suryawanshi², Sanika Jadhav³
Nandini Tribhuvan⁴, Priyanka Shivalkar⁵

^{1, 2, 3}Dept of computer engineering

⁴Dept of Artificial intelligence and Data science

⁵Dept of vlsi design and technology,

^{1, 2} VivekaSinhgad institute of technology, Lonavala, India

^{3, 4}Ajeenkya Dy Patil School of Engineering, Pune, India

⁵AISSMS College of engineering, Pune, India

Abstract- *With abundant availability of solar energy year-round, the country has ample scope for using solar power to meet its growing energy demands. Solar panels are thus gaining popularity in India and playing a crucial role in its energy transition. This paper studies the usage of solar panels in rural and urban areas, highlighting their application and overall impact.*

Rural communities make use of solar panels for basic lighting purposes, as well as irrigation purposes. On the other hand, the primary drivers of adoption in urban communities include rising electricity prices and increased environmental awareness. The paper will look into various factors associated with this issue, including benefits and constraints.

Among several benefits, reduction in dependence on fossil fuels, decreased carbon footprint, and financial savings are mentioned as some of the key benefits. Constraints include initial installation costs, lack of awareness among communities in certain locations, as well as maintenance issues.

The paper will analyze the financial feasibility of solar panel adoption in India, demonstrating that the cost of installation would be recovered within a relatively short period of time. It becomes clear that further adoption in this regard requires raising awareness levels among communities.

Keywords: Solar Panels, Renewable Energy, Rural Electrification, Sustainable Development, India

I. INTRODUCTION

It goes without saying that energy is an essential component in the development of a country, including India. Due to the ongoing process of industrialization, urbanization, and demographic growth, there was a sharp increase in electricity demand over the past decades. Typically, this electricity was generated by means of fossil fuels such as coal

and petroleum, which are finite resources and highly pollutant. Thus, there was an obvious need to look for sustainable alternatives.

In this regard, solar panels seem to be an effective solution, especially considering that India enjoys a favorable geographic location, which allows generating substantial amounts of solar energy all year round. Taking into account its advantages, the Government of India initiated numerous projects aimed at promoting solar energy, including the Jawaharlal Nehru National Solar Mission [1]. These measures resulted in an impressive expansion of the capacity of solar power plants in India.

Reports from bodies such as the International Energy Agency and World Bank reveal that India has become one of the quickest growing countries for solar energy production and investment [2], [3]. Reports from the International Renewable Energy Agency further suggest that the use of solar energy would help meet future demands for energy and lower greenhouse gas emissions [4].

The application of solar panels in India differs considerably between rural and urban settings. Solar panels have been applied extensively in rural settings as a source of light and energy supply for water irrigation and other uses where there is no provision for the electrical power grid. The use of solar panels for electricity generation has been encouraged through government initiatives and reported by the Central Electricity Authority [5].

In urban settings, the installation of solar panels has mostly been motivated by economic considerations such as electricity tariff increases and energy efficiency considerations.

Recent studies by NITI Aayog and REN21 have indicated that although India has shown substantial progress in the utilization of solar energy, there remain hurdles related to

high installation costs, insufficient awareness, and infrastructural constraints [9], [10].

It is imperative at this point to analyze not just the expansion of solar energy systems but also their implementation under real-life circumstances. This research aims to offer insights into the adoption process of solar panels in both rural and urban India by examining their applications, advantages, drawbacks, and economic viability.

OBJECTIVES OF CASE STUDY –

- a) To conduct an analysis of the real cost of setting up solar panels for individual households.
- b) To find out how much savings will be made annually by lowering the costs of electricity bills.
- c) To calculate the payback period with the help of an example.
- d) To find out the cost of electricity before and after setting up the solar panels.
- e) To learn about the feasibility of using solar panels in practical life.
- f) To find out about the long-term advantages of using solar panels.
- g) To find out about the practical application of solar panels in real life.
- h) To understand how the use of solar panels decreases the use of non-renewable sources of energy.
- i) To make the idea of solar panels more understandable and simple. To bridge the gap between theoretical analysis and real-life application.

II. LITERATURE REVIEW

In India, the growth of solar energy has been shaped by various policies and the rise in global interest in renewable energy sources. The first notable policy in this regard was the Jawaharlal Nehru National Solar Mission, which set a strategic framework for the deployment of solar energy and motivated investors [1]. This policy helped lay down the long-term vision for solar energy in the country.

Various international reports have pointed out that India is among the most promising countries for developing solar energy sources. For example, the International Energy Agency has predicted that India will be one of the most influential countries contributing to global solar energy capacity owing to favorable climatic conditions and energy demand [2], [8]. Likewise, the World Bank has stated that investments in the Indian solar sector have been increasing

since its inception, reflecting promising opportunities for future development [3].

The International Renewable Energy Agency has stressed that besides helping reduce greenhouse gases, solar energy could enhance energy security in the country by lowering the reliance on energy imports. In light of these benefits, it is crucial to deploy solar panels as part of sustainable development efforts globally.

The national figures provided in reports by the Central Electricity Authority demonstrate a constant rise in solar power generation, which shows the effectiveness of policies and measures taken by the government [5]. According to reports of NITI Aayog, developments in technology and favorable policy measures have contributed to an increase in the popularity of solar power generation since 2015 [9].

Moreover, the global research conducted in the area by REN21 reveals that India is among the leading growing countries in terms of the development of renewable energy market, especially the part related to solar power generation [10]. Reports indicate that declining prices and supportive policies facilitated increased adoption of solar energy.

Nevertheless, despite all the positive changes, existing literature provides numerous factors that can prevent the widespread use of solar power generation. First of all, there are high expenses associated with installation, low awareness of people residing in rural regions, and insufficient infrastructure, among others.

From a general perspective, it appears that India has done well to develop solar energy, but the country falls short of realizing its full potential for solar energy adoption. The research presented here is an extension of such results in that it compares the patterns of solar energy adoption in rural and urban areas.

III. METHODOLOGY

In this study, a descriptive analysis methodology has been adopted that uses secondary data instead of performing field studies and experiments. Considering the fact that the use of solar panels in India has extensively been discussed, it becomes easier to adopt secondary data in order to understand the latest trends. This study is not an experimental one and only aims at providing an analysis of data available from trustworthy sources like governmental and non-governmental organizations and reports. Data collection includes data extracted from official bodies like the Ministry of New and Renewable Energy (MNRE), international energy agencies

like the International Energy Agency and the International Renewable Energy Agency [2], [4], [8]. Other relevant data has been taken from World Bank reports [3], National Capacity Building Reports of Central Electricity Authority [5] and policy analyses provided by NITI Aayog and REN21 [9], [10].

This data was analyzed through the use of comparative, trend, and economic analysis techniques. The comparative analysis involved comparing the use of solar panels in rural areas against those used in urban areas to see how the two vary depending on geographical location. Trend analysis enabled the researcher to analyze trends involving the number of solar panels installed in India with time, with emphasis being placed on policy-based expansions [1], [2]. Economic analysis was conducted through determination of the payback period for solar panels in relation to their use in common scenarios. In an attempt to make results more clear and presentable, graphical presentation has been employed using line graph, pie chart, and bar chart methods. Although the research covered most of the issues surrounding the use of solar panels in India, there were a few limitations associated with the use of secondary data. However, the method used was quite practical and provided an all-inclusive approach to the topic.

IV. GROWTH OF SOLAR PANELS IN INDIA

In the recent decade, there have been noticeable trends in the implementation of solar power generation in India. In the first part of the 2010s, solar panels were underrepresented in the region, but everything changed with the launch of such organized policies as the Jawaharlal Nehru National Solar Mission. It provided specific goals and made solar power generation more widely used. Over time, there have been multiple improvements concerning the implementation of solar panels, as the amount of solar capacity in India exceeded the mark of 100 GW during the mid-2020s [1].

According to the statistics presented by the International Energy Agency, the solar energy market in India has become one of the most rapidly growing in the world with great opportunities for further growth [2], [8]. As evidenced by statistics published by the Central Electricity Authority, the number of installed solar panels increases annually, which is a direct result of active government intervention and improvement of existing infrastructure [5]. The World Bank provides additional financial analysis proving increased funding and installation costs reduction [3].

Moreover, policy lessons derived from NITI Aayog state that advancements in regulatory framework and incentives like subsidies and net metering have facilitated the installation of solar panels for rural and urban consumers [9]. Further validation of this point has been provided by international organizations such as REN21, which have confirmed India's emergence as an important actor in the renewable energy transition, especially concerning the solar sector [10].

While this growth trajectory is remarkable, it should be noted that its pace has varied across different regions. Some states and urban centers have witnessed more rapid progress owing to greater infrastructure and knowledge about solar panels. In contrast, others continue to lag behind in terms of implementation and adoption. Nonetheless, this observation demonstrates that despite the overall growth in solar panel deployment in India, there is ample scope for further growth and development in this field.

V. ENVIRONMENTAL IMPACTS OF SOLAR ENERGY ADOPTION

Although there is no doubt about the sustainability of solar energy as opposed to traditional forms of energy, it is essential to evaluate both the pros and cons of how this source of energy will affect the environment. In the context of assessing the environmental pros and cons of using solar photovoltaics, one must be aware of the dual nature of solar energy.

Firstly, the reduction of greenhouse gas emissions stands out as the greatest environmental benefit of solar energy. Solar PV does not release carbon dioxide and other toxic chemicals, which helps reduce global warming and air pollution [1][2]. It stands out from traditional electricity generation processes through the use of fossil fuels in this regard. As noted above, the environmental advantages of rooftop solar PV are associated with the fact that it does not require new land and makes use of existing infrastructure. In addition, the use of solar energy contributes to the sustainable development of the economy due to minimal dependence on traditional energy sources, such as coal and oil. Another benefit of using solar energy is associated with its low consumption of water compared to thermal plants [11].

But, at the same time, one cannot ignore the fact that the systems used for harnessing solar energy are not free from any environmental impact. One of the major concerns about using this energy source concerns land use, since large solar plants require much space and contribute to the disruption of the ecological balance as well as loss of biodiversity [7]. The

production process of solar panels includes several chemicals, which means that it contributes to further environmental pollution and emission levels [3][6].

Another emerging problem associated with the use of solar energy concerns e-waste, which is created when the panels reach their operational capacity and need replacing. Because of the hazardous substances contained in the panels, their incorrect disposal will cause contamination of the environment, which becomes increasingly important due to the wide-scale use of this type of energy, particularly in developing nations that have no appropriate recycling infrastructure [6][7]. Furthermore, due to its intermittent nature, solar energy should be complemented by other types of energy sources, including batteries.

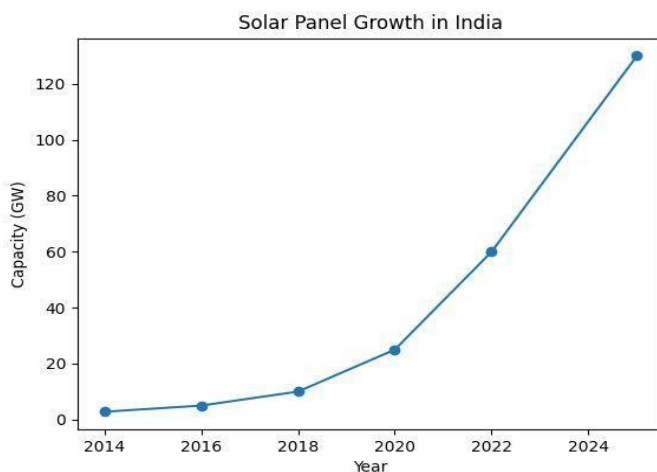


Figure 1: A line graph showing exponential growth in installed capacity over time.

VI. SOLAR PANEL ADOPTION IN RURAL INDIA

The use of solar panels in rural areas is usually determined not by choice but by necessity. For instance, there are still many villages that lack stable power or, worse yet, have absolutely no connection to the electricity grid at all. In this regard, solar panels come to the rescue as the only viable option. There have been numerous government-led efforts to introduce solar power in rural communities, particularly through the National Solar Mission program, which encouraged its use for irrigation and domestic power supply [1].

Perhaps the most prominent application of solar panels in rural areas is agricultural use, where solar pumps have proven useful in helping farmers minimize their reliance on diesel fuel, thus saving money and reducing pollution. As reported by the Central Electricity Authority, decentralized solar energy systems are gradually gaining momentum in boosting energy security in distant rural communities [5].

Apart from farming, solar lamps are commonly installed to light up homes, facilitating everyday activities such as studying, cooking, and even working.

A further noteworthy trend is the use of solar-based street lighting and micro-grids in rural communities. Such systems help increase security and working hours, as well as boost small-scale entrepreneurship in some cases. As per studies cited by the International Renewable Energy Agency, solar-based decentralized approaches prove to be highly efficient in areas where it is complicated or costly to develop conventional grid extensions [4].

Nevertheless, despite all the advantages mentioned above, the use of solar panels in rural India encounters various obstacles. For instance, insufficient knowledge, technical literacy, and maintenance problems might affect the efficiency of solar systems. As mentioned in reports published by NITI Aayog, although subsidies and programs are offered, their distribution across different states remains uneven [9]. In addition, economic problems might hinder the acquisition of even subsidized installations.

Overall, the application of solar panels in rural areas of India proves to be quite encouraging. Thus far, solar panels have proven to be beneficial for energy provision and agriculture. Nevertheless, further improvements are required to enhance knowledge and skills related to the use of solar technologies.

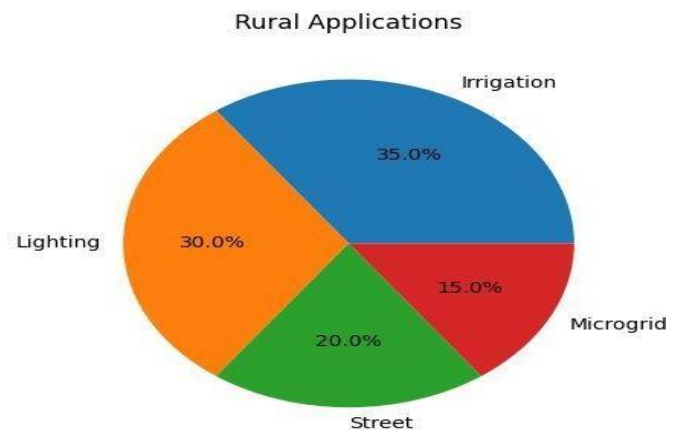


Figure 2: Distribution of Solar Panel Applications in Rural India

VII. SOLAR PANEL ADOPTION IN URBAN INDIA

Solar panels are adopted in urban India not because of accessibility challenges but rather because of economic incentives and environmental consciousness. Although all Indian urban areas are powered by electricity grids, the high rates of electricity and its growing demand in the cities have

compelled consumers to consider other sources of energy. In this regard, rooftop solar installations have gained popularity among middle- and upper-class consumers who seek to cut their electricity expenses.

Government programs have facilitated this transition. Programs such as those initiated under the National Solar Mission and the introduction of net-metering policies have provided opportunities for urban consumers to use solar panels not only for their own consumption but also to sell surplus energy to the grid [1]. As stated in the reports of the International Energy Agency, the Indian urban solar industry will experience steady growth due to growing consumer awareness and decreasing installation costs [2], [8].

Solar paneling has also been embraced by commercial enterprises, like office spaces, malls, and industrial firms. This move is not motivated by environmental concerns alone but also by financial benefits that accrue to firms in the long run. Research sponsored by the World Bank reveals that better finance models, coupled with lower costs associated with solar power production, are driving the use of solar energy in cities [3].

NITI Aayog's recommendations also reveal that urban adoption of solar energy is highly dependent on such factors as awareness, simplicity, and the availability of incentives [9]. On a wider note, international organizations, including REN21, confirm that solar roof top energy plays a vital role in sustainable urban development [10].

Nevertheless, urban use of solar panels is not entirely free from drawbacks. Space issues in highly congested urban areas, substantial upfront cost, and the complex process involved with installation could deter some individuals. Maintenance and inconsistent energy output due to changing weather are additional factors that should be taken into consideration. As can be seen, the use of solar panels among urban Indian communities is constantly rising, as it provides both financial advantages and ecological benefits. Although much progress has been achieved in recent years, there are ways to improve solar panel adoption in cities even further..

VIII. GOVERNMENT INITIATIVES

It should be acknowledged that the proliferation of the utilization of solar panels has not happened in India without adequate state-level support. In time, several state policies and programs were established and implemented, all aimed at encouraging the adoption of solar energy both in rural and urban settings. One of the crucial milestones in this regard was the launching of the Jawaharlal Nehru National

Solar Mission, a project outlining ambitious targets related to solar capacity and an effective development pathway [1].

At the same time, the government took care to address the question of financial accessibility, as the costs of installation constitute one of the biggest hindrances to the adoption of solar panels. The reports published by NITI Aayog reveal that financial support initiatives had played a crucial part in ensuring an increase in the number of adopters of solar panels, especially residents [9].

In the rural sector, certain programs have been designed to cater to agriculture and off-grid applications. Programs that encourage the use of solar pumps and localized solar energy systems are part of these initiatives. Data provided by the Central Electricity Authority reveals that these programs have resulted in increased electricity access in far-flung areas [5]. Such measures play a vital role in places where it is impractical or expensive to extend grid facilities.

The rules for net metering in urban areas have ensured that rooftop solar panels are financially feasible for people. It is not just enough that the individual becomes self-sufficient with the help of solar energy; rather, he/she can sell any excess energy generated back to the power grid. Studies carried out by the International Energy Agency prove that the right set of policies has helped to increase the popularity of rooftop solar panels in urban cities [2], [8].

Assessments carried out by REN21 suggest that due to its strong policy orientation, India has emerged as one of the top countries when it comes to renewable energy development [10]. However, in spite of these achievements, several challenges, including inadequate implementation, insufficient awareness in some areas, and procedural delays, still remain.

On the whole, the Indian government has done a lot in terms of promoting the use of solar panels. Though a lot of work has been accomplished, more emphasis will need to be put on creating awareness and making things more accessible.

Projected Growth in Installations under PM Surya Ghar: Muft Bijli Yojana

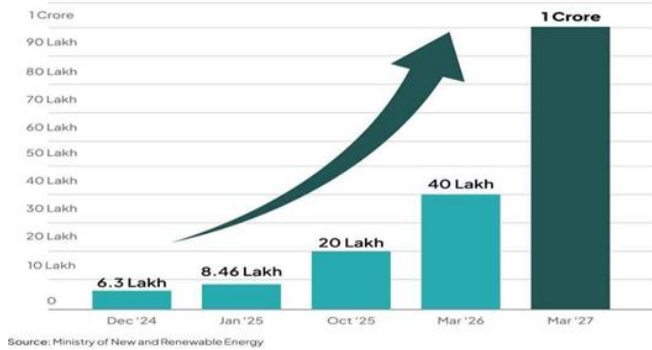


Figure 3: Projected Growth of Solar Panel Installations under PM Surya Ghar: Muft Bijli Yojana

IX. CHALLENGES IN SOLAR PANEL ADOPTION

Despite the advantages of solar panels, their usage in India continues to face some obstacles. It turns out that, despite obvious benefits, there are many practical hurdles that make the spread of solar panels slow.

The most prevalent problem is the cost associated with installation. Although costs have been decreasing over time, they can still be quite high for average homeowners. According to World Bank reports, financing issues remain one of the biggest problems facing solar energy development, especially among low-income communities who do not have adequate access to financing [3].

Secondly, the general lack of awareness and knowledge also hinders the growth of solar energy. Some individuals lack information about benefits while others are skeptical of the technology due to a general lack of understanding of how solar energy works. As indicated by NITI Aayog sources, awareness remains an issue [9].

The technical aspect also has its limits, particularly regarding energy storage. Given that solar panels produce power during daytime hours, it becomes necessary to store energy for nighttime usage or on cloudy days, which demands batteries, an expensive option requiring maintenance regularly. As pointed out by the International Renewable Energy Agency, the advancement of storage systems is crucial for ensuring reliability of solar power generation [4].

Space availability may prove to be a constraint in the case of urban settings. Buildings do not always possess adequate rooftop area to install solar panels, especially in highly dense urban centers. Also, the procedures involved in installations and acquiring permissions might make the process tedious for users.

Maintenance support and post-sale services are another issue. In many instances, particularly in remote locations, it might become difficult to source professionals for conducting repairs. According to data provided by the Central Electricity Authority, the infrastructure support is gradually improving across different regions of the nation [5].

Similarly, international studies conducted by agencies like the International Energy Agency and REN21 also note that although policies are in place, inconsistencies in implementation and regional differences may pose obstacles to adoption [2], [10].

In summary, despite the great possibilities solar panels present, it is clear that for adoption to occur effectively, factors like awareness, accessibility, and policy enforcement must also be considered. Overcoming these barriers will be essential in making solar energy available to more people in India.

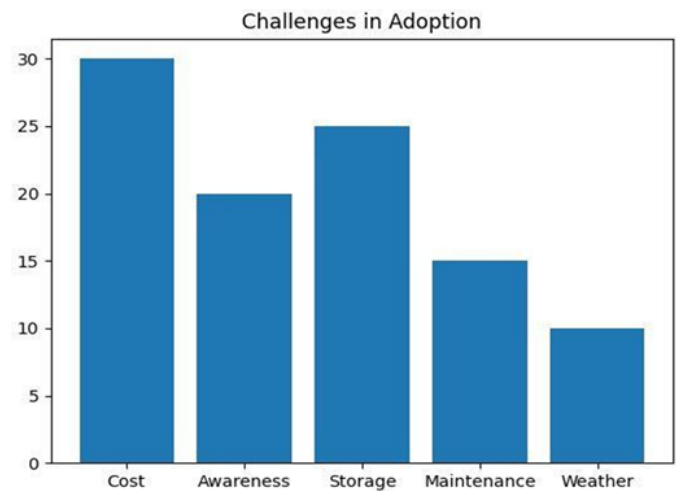


Figure 4: A Bar chart showing the major challenges In Solar Adoption.

X. PAYBACK PERIOD OF SOLAR PANELS

One of the practical considerations when deciding to install solar panels is, “What is the payback period?” The payback period is a term that explains how long it takes to break even after installing solar panels. Simply put, the payback period is the duration taken for the savings achieved by using a solar panel system to cover its cost of acquisition.

Over the past few years, the cost of installing a small residential solar panel system in India has dropped. This reduction can be attributed to technological innovations and government interventions [1]. Various studies conducted by the International Energy Agency indicate that the decreasing

cost of installation and increased efficiency of solar power systems have made them more affordable for individuals [2], [8].

In the case of a common rooftop solar plant of 1 kW capacity, the cost of installation is between ₹45,000 to ₹60,000 even after accounting for subsidies. This system has the capability of generating approximately 4 to 5 units of energy per day, which amounts to about 1,500 units per year. According to average electricity rates, the annual savings from this system would be approximately ₹9,000 to ₹12,000. The economic evaluations backed by the World Bank have shown that such savings make solar panels a feasible investment [3].

Based on the above information, the payback period can be computed. For instance, if the cost of the system is ₹50,000 and the saving potential is ₹10,000 per annum, then the payback period will be approximately five years. Once this period has elapsed, the system will produce free electricity until its end-of-life period, which is normally twenty to twenty-five years. According to the reports by International Renewable Energy Agency, long system lifetimes greatly contribute to higher financial gains [4].

However, in urban places, the cost of electricity is relatively high and hence the payback period will be much shorter and may vary between 3-4 years. On the other hand, in rural places, the payback period takes slightly longer because the cost of electricity is lower, though various programs by the government are able to close the gap. From the policy insights drawn by the NITI Aayog, it is evident that subsidies and incentives have a significant impact on lowering the payback period [9].

From the analysis above, it is clear that solar panels have a relatively low payback period compared to other forms of energy generation. This implies that solar panels are environmentally friendly and economically feasible.

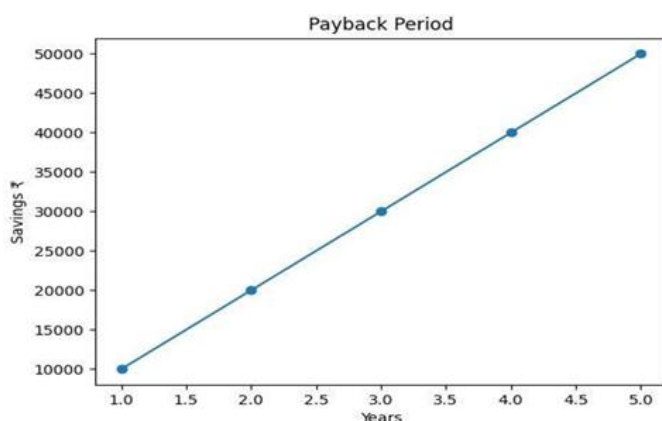


Figure 5: Payback Period Analysis of Solar Panel System

XI. DISCUSSION

Taking a look at the results collectively, one thing is obvious – the adoption of solar panels is on the rise not only in terms of quantity but in terms of significance too. Nevertheless, its adoption varies from one region to another significantly, and for that reason, it is crucial for us to distinguish between urban and rural areas if we are to gain an overall perspective.

The case in rural areas is that people are adopting solar panels in order to tackle one primary issue – electricity. As you see, in numerous villages where power supply through the grid is unavailable or erratic, these systems act as a source of energy that can be used to fulfill basic necessities like lighting and irrigation purposes. Thanks to government schemes and agricultural projects [1], [5], this adoption is being encouraged widely.

Urban areas have their own set of facts. In such settings, the deployment of solar panels is a matter of choice rather than necessity. Rising energy prices and the prospect of saving money in the future are some of the main motivations of people. As far as installation of rooftop solar power systems goes, more and more houses are considering doing so in view of their affordability. According to the reports published by the International Energy Agency and REN21, this trend will persist in the future as well [2], [10].

Moreover, it is the economic considerations that are significant in making decisions regarding adopting solar panels. The payback period calculation has confirmed that in addition to being environmentally friendly, it also makes economic sense to use them. Moreover, the recovery of the initial investment within a very short span of time enhances their appeal. This has been validated by research backed by the World Bank [3].

Nevertheless, it is imperative to mention the difficulties that were noted before. The issue of high cost, the problem with lack of awareness, and especially technical difficulties, associated with the question of battery storage of electricity generated by the panels, cannot be overlooked either. NITI Aayog provides an explanation that it is not sufficient to provide policy support only – implementation and awareness are necessary for this purpose as well [9].

Also, there is another curious detail: although India managed to increase its number of installed solar power capacity greatly, this process is rather unevenly distributed. There are some regions where rapid development takes place

and some that are lagging behind. Hence, one can assume that local conditions have a great impact on solar panel adoption.

In general, the review of the topic clearly demonstrates that the use of solar panels becomes an essential part of the Indian energy landscape, but the adoption of them has a complex nature.

XII. CONCLUSION

In conclusion, it can be stated that solar panels have definitely gone beyond alternative technologies in meeting India's energy requirements. The most important thing to note here is that they are being used in different ways all around the nation. While they are solving the problem of basic electricity provision in rural parts of India, in the urban sector, they are being used for saving electricity bills and promoting sustainable energy usage.

According to the findings of the research, governmental interventions in solar panel installations in India have been quite significant and have contributed greatly to their popularity [1]. However, the decrease in the cost of installation and rising awareness have certainly played a significant part as well. Moreover, information provided by international organizations supports the assumption that India is following the right course to increase its solar power generation capacity [2], [10].

From the economic perspective, payback period analysis demonstrates the financial sense of using solar panels besides their ecological advantage. The possibility of recovering the cost of installation during the first few years and receiving subsequent savings proves their financial benefit for many customers. As is supported by information provided by the World Bank, cost saving is the factor determining adoption decisions [3].

Nevertheless, there are still aspects that should be taken into consideration since they pose difficulties to solar panels' widespread usage. It concerns issues like the problem with their high cost, low levels of awareness in some areas, as well as technical problems with storage. NITI Aayog reports that it becomes necessary to find ways to implement policies more effectively as well as raise public awareness [9].

Finally, solar panels may have a significant impact on the development of energy supply in India. With appropriate measures, they can become an alternative to traditional sources of energy and contribute to the country's transition to sustainable development.

REFERENCES

- [1] Ministry of New and Renewable Energy (MNRE), Government of India, "Jawaharlal Nehru National Solar Mission Phase- II Policy Document," New Delhi, India, 2014.
- [2] International Energy Agency (IEA), "India Energy Outlook 2015," Paris, France, 2015.
- [3] World Bank, "India's Solar Power Growth and Investment Report," Washington, DC, USA, 2014.
- [4] International Renewable Energy Agency, "Renewable Energy Prospects for India," Abu Dhabi, UAE, 2014.
- [5] Central Electricity Authority (CEA), "Power Sector Report," Government of India, 2015.
- [6] Ministry of New and Renewable Energy (MNRE), Government of India, "Annual Report 2024-25," New Delhi, India, 2025.
- [7] Ministry of Statistics and Programme Implementation (MOSPI), "Energy Statistics India 2025," Government of India, 2025.
- [8] International Energy Agency (IEA), "India Energy Outlook 2024," Paris, France, 2024.
- [9] NITI Aayog, "Renewable Energy in India: Progress and Challenges," Government of India, 2023.
- [10] REN21, "Renewables Global Status Report 2024," Paris, France, 2024.