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Research Article

Solar Energy Consumption And Economic Growth Of Farmers In North India - A Way Towards Ecological Sustainable Economy

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ABSTRACT

In North India, agriculture plays a pivotal role in the economy and sustenance of rural communities, yet it faces challenges of sustainability amidst rising energy demands and environmental concerns. This study examines the potential of solar energy adoption among farmers as a catalyst for economic growth and ecological sustainability. Through a mixed-methods approach incorporating surveys and qualitative interviews, data will be gathered to analyze the current state of solar energy consumption among farmers and its impact on economic indicators such as income levels, productivity, and cost savings. The research aims to fill gaps in existing literature by focusing specifically on the North Indian context, where solar energy adoption remains underexplored despite its potential benefits for both economic development and environmental conservation. Findings are expected to provide empirical insights into the viability of solar energy as a sustainable energy source in agriculture, offering implications for policy makers and stakeholders seeking to foster an ecological sustainable economy in the region.

Keywords: Renewable Energy, Solar Energy, Economic Growth, Ecological Sustainability

Introduction

As a result of the fact that it offers a means of sustenance and helps to the expansion of rural regions, agriculture is an essential component of the economy in Northern India. Nevertheless, the industry is presented with major challenges, which are made even more severe by the use of conventional energy methods and the degradation of the environment. There are a number of issues that are associated with sustainability that are being faced by the agricultural sector of the region, which is mostly reliant on fossil fuels and electricity provided by the grid. These challenges include growing costs and the impact that it has on the environment. Renewable energy sources, and solar energy in particular, have emerged as promising choices to lessen the degradation of the environment and to strengthen economic resilience in response to these concerns. Solar energy is particularly noteworthy in this regard. However, despite the fact that there is a global trend towards the use of renewable energy sources, the adoption of solar technology among farmers in North India continues to be limited and unevenly distributed. This is despite the fact that there is a worldwide drive towards the use of renewable energy sources. Given this, it is of the highest significance to investigate the prospect of adopting solar energy as a new way for encouraging economic growth while simultaneously increasing ecological sustainability in agriculture.

This is because solar energy has the potential to be environmentally friendly. When farmers make the switch to solar energy, they not only reduce their reliance on conventional energy sources, which are not only costly but also hazardous to the environment, but they also have the potential to increase their productivity through the implementation of improved irrigation systems, increased mechanisation, and increased agricultural yields. Additionally, the use of solar energy has the ability to contribute to the diversification of income and the elimination of poverty in rural agricultural areas. As a result, it has the potential to support socio-economic growth in combination with environmental stewardship. By performing an in-depth analysis of the link between the utilisation of solar energy and the economic implications encountered by farmers in the northern area of India, this research tries to provide a solution to these problems. Through the use of a comprehensive research approach that incorporates both quantitative surveys and qualitative interviews, the purpose of this study is to shed light on the socio-economic repercussions that results from the implementation of solar energy. In addition, the study intends to identify obstacles to implementation and propose policy solutions in order to cultivate an agricultural economy that is both robust and sustainable in the area.

Objectives of the Study

i) To analyze the growth of solar energy in India.
ii) To find out the impact of solar energy expansion on the economic growth of India.
iii) To examine the role of solar energy expansion on ecological sustainability of the economy.

Review of Literature

Ranganath, N., & Sarkar, D. (2021) India is analyzing renewable energy systems using Life-Cycle-Costing (LCC) to determine their technical and economic viability. The country aims to create 100 gigawatts of solar power capacity by December 2022, demonstrating the low cost of renewable energy systems. Six solar power facilities in six Indian states were assessed, showing high technological and financial feasibility, with return on investment typically under eight years.

Ivanovski K. et al. (2021) The study used locally linear dummy vector estimation (LLDVE) to analyze data from OECD and non-OECD panels from 1990-2015. It found that nonrenewable energy sources contribute to economic development in OECD countries, with the coefficient function growing over time. Non-OECD countries' economic success demonstrates that developing nations can help transition to renewables despite technological barriers.

Mishra T. et al. (2020) Uttarakhand's rooftop solar PV potential is estimated to be 57% of the state's electricity needs if all high-irradiance roof space is used. The state receives over 4 kWh/m2/day of solar radiation year-round, with a median panel efficiency of 15%. The plain area has generated 27.47 GWh of electricity from 234.4 MW of ground-mounted and 5.9 MW of rooftop solar PV systems.

Khan, S. A. R. et al. (2020) A study by the World Bank found that integrating renewable energy in logistics can reduce emissions and improve environmental and economic performance. This suggests that environmental sustainability can benefit both human health and economic development. Rising public health costs and poor environmental performance can hinder economic growth, but integrating renewable energy can enhance sustainability, national image, and export potential.

Nandal V. et al. (2019) The current power infrastructure in India is inadequate to meet the country's energy needs, making it an ideal candidate for solar power. This study examines solar energy usage in India's thermal power plants and identifies major obstacles such as massive investments, slow recovery, safety concerns, environmental concerns, and societal issues. Insufficient government policy and political leadership are the greatest obstacles to a systematic strategy.

Krishna K. Pandey & Harshil Rastogi (2019) In particular, the impact of rising energy consumption and GDP on pollution and other forms of environmental damage is investigated. It was discovered that there is a cointegration vector between economic growth and CO_2 emissions. Industrial, agricultural, residential, commercial, and railway sectors were all found to have cointegrated CO_2 emissions and power consumption. According to the research, India has to do something drastic to stop the growing emissions of greenhouse gases, especially CO2.

Santosh Singh Raghuwanshi & Rajesh Arya (2019) The following percentages of India's total energy potential have been realised: 56.37 percent from wind, 7.60 percent from small hydro plant projects, 14.5 percent from biomass, 21.46 percent from solar, and 0.30 percent from other resources. The state of Tamil Nadu in the south and the Indian states of Maharashtra, Gujarat, and Rajasthan in the north have the greatest capacities for wind and solar electricity, respectively. Renewable energy and energy management are two areas that the Indian government should prioritise, according to the report.

Sinha, A., & Shahbaz, M. (2018) The study calculates India's "EKC" for CO2 emissions from 1971 to 2015 using renewable energy production methods. Findings show an inverted U-shaped EKC, with a negative impact on CO2 emissions and international trade. The study offers policy recommendations for reducing emissions.

Zafar, Muhammad Wasif and Shahbaz, Muhammad and Hou, Fujun and Sinha, Avik (2018) The research looked at the APEC nations' economic development from 1990 to 2015 and how different energy sources, renewable and non-renewable, affected it. Renewable energy has a good effect on economic development, and it was discovered that there is long-term cointegration. Trade openness and investments in R&D also had a good effect on growth. Consumption of renewable energy sources is positively associated with GDP growth, according to the Granger causality study. If we want long-term economic development, the report says we should put more money into renewable energy.

Ross Gillard, Andrew Sudmant, Andy Gouldson, and Lucy Oates (2018) A study reveals that rooftop solar power in cities is crucial for achieving SDG-7 by 2030. The study, based on interviews with 15 stakeholders, found that Delhi's flexible incentives and single point metering system make rooftop solar more affordable. The government's role in setting renewable and solar agendas is to provide economic incentives and enable innovative policy implementation.

Sasana, H., & Ghozali, I. (2017) The research compared the effects of fossil fuels and renewable energy on GDP expansion in BRICS countries. Results showed that coal usage significantly contributed to BRICS economies' expansion, while renewable energy usage slows them down.

Kuldeep, Neeraj, Kanika Chawla, Arunabha Gosh, Anjali Jaiswal, Nehmat Kaur, Sameer Kwatra and Karan Chouksey (2017) reviewed the renewable energy sector's employment prospects, both now and in the future. Annual studies of the wind and solar sectors in India formed the basis of this report. Solar and wind power generated more than 21,000 jobs in 2016–17 and are projected to provide another 25,000 jobs in 2017–18, according to the report. According to the survey, solar employment are spread out throughout the nation, whereas wind jobs are concentrated in only a few areas. The report recommended that in order to create more jobs, the government should encourage the growth of the domestic solar manufacturing sector and fund the establishment of wind power training facilities.

Sindhu S. P. et al. (2016) observed that solar energy usage has increased in India but that this increase is still insufficient. Since its inception, it has faced several challenges. Solving these issues requires a firm grasp of the challenges inherent in solar power. The study aimed to identify the barriers to solar power expansion in India and rank them in order of importance using "AHP (analytical hierarchy process)." When comparing the many issues identified, "Political and Regulatory Barriers" stands out as the most significant. Additionally, sensitivity analysis is performed to see how consistent the rank of solar industry difficulties really is. Methods for overcoming these obstacles are also provided.

Kumar, S., & Madlener, R. (2016) The Indian power sector faces pressure to provide sustainable, affordable electricity due to rising demand, especially in summer. The majority of power comes from fossil fuel plants, causing greenhouse gas emissions. Renewable energy sources can provide pollution-free power. The LEAP energy model suggests that by 2050, ARET could decrease CO2 emissions by 74%.

Luthra S. et al. (2016) analyzed the developments in Indian solar power to determine whether or not these developments will lead to higher consumption in the present-day Indian setting. Based on the data and input of solar industry experts, this study identifies sixteen solar power boosters. Major drivers of solar power expansion were assessed and categorized using a fuzzy decision-making approach developed at the "Decision Making Trial and Evaluation Laboratory (DEMATEL)." The fuzzy DEMATEL approach can deal with the unknowns when looking at enabling links. Researchers have found that changes in the energy sector (E12) and measures at the state level (E7) promote the expansion of solar power in India. In order to aid in the growth of solar power, this study analyzed enablers, causal linkages, and their interactions.

Mahtta R. et al. (2014) highlighted the potential for CSP and "SPV(Solar Photovoltaic Program)" power plants in India by the district. NASA's surface meteorology and solar energy programs recorded "global horizontal irradiance (GHI)" and "direct normal irradiance (DNI)" from space every year to use as benchmarks for this evaluation. Unfavorable locations for solar energy production were omitted using a GIS by assessing GHI, DNI, land-use data, and "digital elevation models (DEM)." Using the land-cover factor, available sunlight, and conversion efficiencies, we calculated the technological potential for solar power generation at appropriate land sites.

Purohit I. et al. (2013) The "Jawaharlal Nehru National Solar Mission" aims to have 20,000 MW of grid-connected solar power plants with 50% CSP capacity by 2022. A study in Northwestern India found that the country's potential for CSP exceeds 2000 GW, with a technological potential of 1700 GW at 1800 kW h/m2, and an economic potential of 700 GW at 2000 kW. Lower DNI sites could become profitable with new technologies and government incentives.

(Muneer et al., 2005) studied "Sustainable production of solar electricity with particular reference to the Indian economy" and said that The environment is suffering as a result of the rapid depletion of fossil fuel sources, which are already under stress. The majority of harmful compounds are manufactured by the energy sector. One quick-to-implement sustainable energy alternative is solar electricity. Hydrogen is often considered to be the optimal energy vector for storing and dealing with intermittent renewable power sources. More than 90% of India's projected energy demand—driven by the country's massive population and rapid economic development—is expected to come from fossil fuels.

(Garg, 2012) studied "Energy Scenario and Vision 2020 in India" and said that With 1.2 billion people calling it home, India is the seventh most populous nation in the world. However, the country's large installed power capacity and high electricity demand pose serious energy problems. With an expected nominal GDP of more than $2 trillion by 2012 and an increase in energy consumption of sixteen times in the last 60 years, India is now the world's fifth-highest energy consumer.

(Devi et al., 2017) studied "Crop residue recycling for economic and environmental sustainability: The case of India" and said that With cereals as the top crop residue producer and sugarcane a close second, India produced a substantial quantity of agricultural waste in 2014–15. Crop residue from paddy rice straw had an estimated 486,955 MW of energy potential in 2014–15, while coarse cereals had a 226,200 MW potential.

(Manju & Sagar, 2017) studied "Progressing towards the development of sustainable energy: A critical review on the current status, applications, developmental barriers and prospects of solar photovoltaic systems in India" and said that Powering India's rapidly growing economy is a reliable source of energy, mostly derived from fossil fuels. Even more people—74 million—live in rural regions without access to modern lights, and about 84 million people still rely on traditional biomass as their main energy source. Significant progress in renewable energy is necessary to get sustainable energy. Solar photovoltaic systems are being encouraged by policies and incentives in India due to the underutilization of the country's extensive renewable energy resources. This research takes a look at solar power in India, including its origins, current growth rate, and potential future developments. In order to hasten the growth of renewable energy sources, it also identifies challenges and offers solutions.

(Patel et al., 2019) studied "Co-Generation of Solar Electricity and Agriculture Produce by Photovoltaic and Photosynthesis—Dual Model by Abellon, India" and said that With the goal of improving energy and food security in rural areas, Abellon Clean Energy has built a 3-megawatt solar power facility for agricultural use. Solar panels are washed, agricultural crops are irrigated, and carbon dioxide is captured in vegetables in the solar-agri-electric scheme, all of which need water. In order to reduce carbon dioxide emissions over a 25-year period, the project is registered under the clean development method. With 215 workers on board, the initiative could capture 1,600,000 metric tonnes of carbon dioxide per year in India and 143,000 metric tonnes of carbon dioxide per year worldwide.

(Partridge, 2020) studied "Power farmers in north India and new energy producers around the world: Three critical fields for multiscalar research" and said that There are also serious questions about land use, labour, and livelihoods that arise when more and more people, especially farmers, are engaged in energy production. The study contends that eco-swaraj, critical environmental justice, and food sovereignty should guide energy research. Alternative energy sources, ecological regeneration, power and autonomy, social conflicts, and equality are some of the topics that could be illuminated by research in these areas.

(Mahto et al., 2021) studied "Agrivoltaics: A Climate-Smart Agriculture Approach for Indian Farmers" and said that There is a high suicide rate in India because of the problems that the country's growing population has in the agriculture sector due to inefficient practices. This project explores solar farming as a climate-smart agricultural option. Agrivoltaics have the potential to make agriculture more reliable and sustainable by electrically empowering rural areas, conserving water, increasing yields, creating sustainable income, and reducing the need for pesticides. Also discussed are the potential benefits, drawbacks, dangers, and opportunities associated with agrivoltaics in India. The research found that agrivoltaics may help with global commitments, employment, economic stability, and resource protection.

(Thakur et al., 2022) studied "Advancements in solar technologies for sustainable development of agricultural sector in India: a comprehensive review on challenges and opportunities" and said that Due to increasing energy needs, limited fossil fuel supply, pollution, and the fact that the majority of Indians labour in agriculture, the creation of renewable energy sources is of the utmost importance. The country's sufficient and plentiful solar resources have allowed India to achieve remarkable progress in the deployment of solar energy. This study focuses on the possibilities of solar energy in agriculture, namely on technologies for crop drying and solar water desalination. In addition to covering law, research, and upcoming advances, it provides insights for agricultural frameworks and proposes solar technology improvements of the future.

(Batra, 2023) studied "Renewable Energy Economics: Achieving Harmony between Environmental Protection and Economic Goals" and said that This research takes an economic view of renewable energy, analysing its role in lowering GHG emissions, guaranteeing a steady supply of power, and impacting policy and funding choices. Renewable energy's importance in boosting local economies, creating new jobs, and facilitating scientific advancement is highlighted. This article explores the impact of renewable energy deployment on electricity prices, renewable technology cost reductions, and financing options including green bonds and project finance. Governments, corporations, financial institutions, and individual customers must all work together, it says, to speed up the transition to renewable energy.

(Kaur & Bhola, 2023) studied "Indian Economy and Ecology" and said that Dr. Rowan Williams stresses the need of recognising the interconnected nature of economics and the environment. Investing in ecosystem protection helps the economy thrive by lowering the negative effects on the environment. In an effort to promote sustainable growth and lessen environmental threats, the Indian economy is embracing a green economy. This technique is taking over the global green energy market because it improves renewable energy portfolios, makes essential services more accessible, and impacts environmental laws positively. The impact of environmental issues on India's GDP is the focus of this essay.

(Supe et al., 2024) studied "Assessment of the solar energy–agriculture–water nexus in the expanding solar energy industry of India: An initiative for sustainable resource management" and said that The Solar Panel Index (SPI) was developed to detect solar farms in India with an accuracy rate of 89%. The study calculated a land suitability index by integrating data on cropland, water availability, power grid, and surface temperature. The findings show that the states of Karnataka and Tamil Nadu have the highest density of solar farms, with more than 40% of these farms situated on farmland. The state and region of Rajasthan stand to gain the most from solar energy installations, which would contribute to their long-term viability.

Research Methodology

This study employs a mixed-methods approach to investigate the impact of solar energy adoption on economic growth among farmers in North India. Quantitative surveys will gather data on solar technology use, economic indicators, and environmental benefits, employing random sampling to ensure regional diversity. Concurrently, qualitative interviews with farmers and stakeholders will explore barriers, facilitators, and perceptions surrounding solar adoption. Data analysis will integrate descriptive statistics and thematic coding to provide a comprehensive understanding of how solar energy influences livelihoods and sustainability in agricultural practices. This methodology aims to offer actionable insights for policymakers and stakeholders seeking to promote sustainable energy solutions in rural economies.

Solar Energy

The light and heat from the sun are the sources of solar energy, and it has many applications. Power may be generated using solar power, water can be heated using solar thermal energy, and buildings can be designed to maximize the use of solar energy in a variety of ways (Duffie & Beckman, 2013). This renewable energy source can be either active or passive, depending on the technology used to collect sunlight, transport it, and ultimately generate electricity. Energy from the sun may be used actively in a variety of applications, including photovoltaics, concentrated solar power, and solar water heating (Basheer 2017). As can be seen in Figure 1, solar energy is converted into usable power by using the "photovoltaic (PV)" effect, which is how solar panels work. It's possible that solar panels might live forever with minimal maintenance (Al-Douri & Abed 2016). The lines that collect the electricity from the panels might be made from copper, silver, or other conductive transition metals that are not magnetic. The cells, as well as the rest of the system, need to be electrically connected to one another.

Figure 1: Schematic diagram of Solar Energy

Source: Alnabi, L. A., & Al-Hakeem, M. S. Stand-Alone Solar Energy Application System: Smart Sunflower Station-Case Study

Photovoltaic Cell

"Photovoltaic (PV)" cells, more generally referred to as solar cells, are electrical components that transform photons, which are particles of light, into usable energy. When light shines upon a "photovoltaic (PV)," or solar cell, also known as a solar cell, it has the potential to be deflected, absorbed, or simply pass through the cell (Khan et al. 2022). Solar cells, or "photovoltaic (PV)" cells, are electronic components that transform energy from photons or light particles into usable electricity. A "photovoltaic (PV)" cell (also known as a solar cell) may either absorb the light that hits it or redirect it in one of three ways (Das & Peu 2022). When a semiconductor is illuminated by light, the material is able to take in the light's energy and then transmit that energy to the material's electrons, which are particles with a negative charge (Meena et al., 2022). That's why electricity is able to flow through matter: electrons have enough energy to make that journey. This current is extracted from the solar cells through their grid-like metal contacts, which conduct electricity. It's possible that this current might supply energy for your home and the rest of the electrical grid.

The sun is the source of energy for photovoltaic cells. Though it's been around for a while, this solar energy system continues to prove itself as one of the most reliable and popular options available (Bosch 2017). Solar photovoltaic energy converts the sun's light into usable energy instead of relying on the sun's heat. A solar cell has three primary layers: the top layer, which conducts electricity, and the layer, which absorbs light. And the rear layer. Both positive and negative electric charges exist in the cell's two electrical layers. The p-type layer, or positive-contact layer, is the layer that facilitates electrical connections (Tabrizi et al. 2021). This layer, located at the front of the cell, is composed of a thin slice of polycrystalline chemical properties that have been adulterated with trace amounts of contaminants. Figure 2 shows a schematic of a photovoltaic cell, which demonstrates how the clean silicon with some impurities in the background electrical interfacial region (negative) cooperates to generate and conduct electricity.

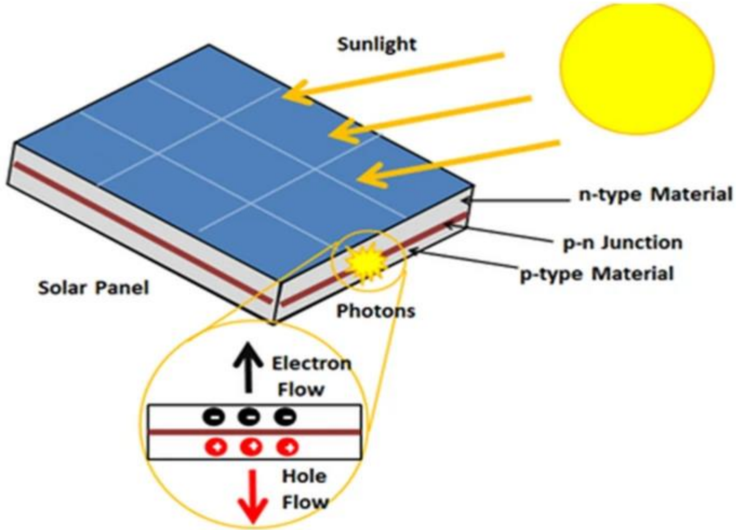


Figure 2. Diagram of Photovoltaic cell
Source: Tabrizi, A. A., Saghaei, H., Mehranpour, M. A., & Jahangiri, M. (2021). Enhancement of absorption and effectiveness of a perovskite thin-film solar cell embedded with Gold nanospheres. *Plasmonics*, *16*(3), 747-760.

Economic Growth of Solar Power In India

The electricity industry is a crucial component of the global economy. Ultimately, the benefits to the end user will only materialize if the power sector does a better job of developing, planning, and executing research initiatives with the support of all utilities (Liu 2018). People worry that the world will run out of oil and other resources in the future because energy use has increased, especially in the last several decades. This has prompted many electrified energy providers around the world to transition from a "vertically integrated" to an "open market" system during the 1990s (Chaudhary et al. 2015).
The overuse of fossil fuels has had observable negative effects on the natural world. The annual human contribution to atmospheric carbon dioxide is around 8 billion metric tons. The combustion of fossil fuels accounts for around 6.5 billion tons, whereas deforestation accounts for about 1.5 billion tons (Mohanty et al. 2017). Rising energy needs in India during the past decade prompted the establishment of the National Solar Mission, which aims to produce 100 GW of solar electricity by 2022. Roughly 60 percent of the National Solar Mission's budget goes to large-scale solar power producers like Indian and other international enterprises. To this end, it is crucial to keep abreast of the actions of major players in the photovoltaic PV industry (Rathore et al., 2018).

Solar Energy and Ecological Sustainability

Solar energy is the important source of renewable energy for providing ample number of economic and environmental benefits. Solar energy is the clean and inexpensive source of energy which contributes in maintaining the ecological balance of the economy. Solar energy generates sustainable electricity without causing air pollution and any global warming emissions.

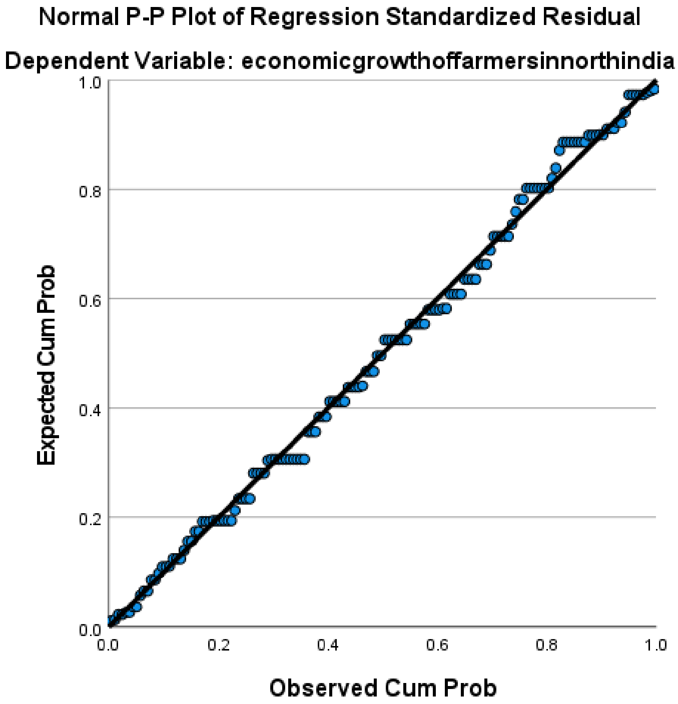
Data Analyze

Model Summary[b]				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.124[a]	.015	.009	.70011

The model summary indicates a weak relationship (R = 0.124) between the predictor variable (solar energy helping to reduce overall energy costs) and the dependent variable (economic growth of farmers in North India). "The coefficient of determination (R Square) suggests that only approximately 1.5% of the variation in economic growth can be explained by the variation in the predictor variable. The adjusted R Square, which considers the number of predictors in the model, is even lower at 0.009, indicating that the model may not adequately account for other factors influencing economic growth beyond the reduction in energy costs attributed to solar energy adoption". The standard error of the estimate is 0.70011, suggesting a considerable amount of variability around the predicted economic growth values. Overall, while the model suggests a statistically significant relationship, the low R Square values indicate that additional variables or factors not included in the model may also play significant roles in explaining economic growth among farmers in North India.

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.130	1	1.130	2.306	.131[b]
	Residual	72.543	148	.490		
	Total	73.673	149			
a. Dependent Variable: economic growth of farmers in north India						
b. Predictors: (Constant), Solar energy has helped reduce my overall energy costs.						

The ANOVA table assesses the significance of a regression model examining how solar energy's impact on reducing overall energy costs relates to the economic growth of farmers in North India. With a regression sum of squares of 1.130 and a residual sum of squares of 72.543, the model's F-statistic of 2.306 yields a non-significant p-value of 0.131, indicating that the model does not sufficiently explain the variation in economic growth based solely on this predictor. This suggests that factors beyond energy cost reduction, not accounted for in the model, likely play significant roles in influencing the economic growth of farmers in the region.



Conclusion

In conclusion, the regression analysis examining the relationship between solar energy's role in reducing overall energy costs and economic growth among farmers in North India shows a statistically non-significant result ($F = 2.306, p = 0.131$). While there is a modest indication of a relationship, the model does not sufficiently explain the variability in economic growth solely based on this predictor. This suggests that other unexplored factors, such as agricultural productivity, market conditions, policy support, and socio-economic variables, likely exert stronger influences on economic outcomes. Further research incorporating these factors is essential for a comprehensive understanding of the dynamics affecting farmers' economic growth in the region.

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