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Research paper

Cost–Benefit Analysis of Solar Energy Utilization in Households: An Economic Evaluation

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Abstract

The advent and rise of electricity as a necessity, and the environmental problems or concerns that accompany the use of traditional fossil-based sources of power, have given the argument in favor of implementing sustainable energy systems in households strong support. Solar energy is now an option with economic and environmental benefits that would be beneficial to the household. Problems with initial establishment cost, opportunity costs, and uncertainty in the financial payoff continue to influence household adoption decisions. The paper shall seek to perform a cost-benefit analysis on the application of solar energy in a household, specifically with respect to the opportunity cost of using solar energy and comparing the economic implications of using solar energy and the traditional consumption of electricity.
This study followed the quantitative research design, whereby a survey of 100 households was carried out with secondary data collection tools such as government and policy reports. The trend in baseline consumption and expenditure was selected through descriptive statistics, and inferential analysis was selected in order to provide more information about financial results. Paired sample t-test compared the expenditure on household electricity in pre- and post-adoption of solar energy, and savings in the new phase were found to be significant. The independent variables of net financial benefits were calculated using multiple regression , where the consumer units of net financial benefits, solar-generated units, imported units, and with- and without-solar costs were important predictors. The opportunity cost estimation indicated that the comparative advantage of investing in solar energy relative to the constant conventional expenditure had a strong effect of 643.22 R on the household savings on a monthly basis, and substantial savings in the dependence on a grid-based power source.
The findings show that though adoption of solar energy is costly in the short run, its economic benefit is higher in the long run, and most importantly, the consumption cost of solar energy is considerably low by its comparison to the use of fossil fuels. Results of studies declare that, in addition to the viability of the economy, the deployment of solar is also strategically feasible in localities where households have an opportunity to save cash and, in addition, ensure that the shifts to sustainability in energy are accomplished. The occupants of the houses will be influenced to make a decision on green energy using the findings, and also sway the debate to implement clean energy in the developing economies.

Keywords: *Solar Energy Utilization; Cost–Benefit Analysis; Household Electricity Consumption; Opportunity Cost; Renewable Energy Adoption; Economic Feasibility; Sustainable Energy Transition.*

1. Introduction

The ever-increasing information regarding the world energy demand has been supplemented by the emerging fears of global warming and the desire to find an alternative to the traditional fossil-fuel-based sources of electricity. Solar energy has been seen as one of the most feasible and extensible modes of power consumption in households owing to its limitlessness, eco-friendliness, and a reduction in the costs of installation. In India, the government has been encouraging solar photovoltaic (PV) system usage by offering incentives, subsidies, and even creating awareness, as electricity consumption within the residential sector accounts for a large proportion of energy demand.
The shift between traditional electricity and solar energy is not rigid throughout the residences despite these measures. Although solar adoption carries inferences of long-term savings on the electric bill, energy security, and a carbon footprint, the initial cost and the cost of an opportunity factor that forms part of the decision-making process are critical aspects. Solar energy systems still experienced a negative financial-risk or technological-uncertainty perception by many households in comparison to conventional grid-based electricity. There is therefore an urgent need to assess the value of the economic gains associated with the use of solar energy in the household, per the costs involved in initiating, maintaining, and the lack of capital in the face of such projects.
The financial feasibility and competitive advantages of solar adoption can be measured by means of a cost-benefit analysis. When considering household-based electricity consumption, the amount of electricity that the sun could theoretically produce, and how much money would be spent on electricity without solar plants or with them, it is possible to identify the economic logic of using solar energy. Furthermore, the opportunity costs of learning, which are the benefits households forego by installing solar systems instead of using traditional electricity, will enhance the assessment of the decision process of households.

The article is dedicated to the economic study of the application of solar energy in households in terms of an integrated cost-benefit analysis. Particularly, it will: (i) identify the opportunity cost of switching to solar energy relative to continued use of regular electricity, and (ii) identify the economic good the switch to solar energy would entail and compare it with the spending the use of regular electricity would entail. These results will inform policymakers, energy planners, and households based on empirical evidence that they can rely on to make decisions on what to do next to ensure more people use renewable energy.

2. Literature Review

2.1. Framing household solar as an economic decision

Residential solar PV is increasingly positioned as a family decision that focuses on tradeoffs between initial cost and future benefit and risk-hedging, as well as co-benefits of reliability/environmental value. Economic assessments tend to be based on cost-benefit analysis (CBA), investment criteria, such as net present value (NPV), internal rate of return (IRR), levelized cost of electricity (LCOE), and simple payback period at the home-level. It is found consistently that viability is particularly sensitive to three levers: (i) the level of tariffs avoided at retail, (ii) cost of capital net of subsidies, and (iii) realized energy yield (generation, self-consumption, and export revenue/credits). In India, different levels of benchmark system costs, consumer-facing subsidies, and evolving metering arrangements (net, gross, net-billing, group/virtual net metering) result in heterogeneity amongst states and consumer groups. Recent data on policy and the market point to a steep growth that develops out of a low base, indicating favorable economics, but also the continued presence of frictions in deployment channels.

2.2. Global evidence on residential solar economics

In cross-national research, the economic behavior of households is highly contingent. With high tariffs and favorable incentives, rooftop PV proliferates in liberalized retail markets with positive NPVs and paybacks; in others with low tariffs and/or damaging interconnection regulations, viability is less favorable. A recent U.S. analysis shows that many households only benefit when incentives and financing terms are attractive; otherwise, returns may be marginal, particularly where retail tariffs are relatively low, and export compensation is modest- again evidence that policy setting and tariff design are determinative to household results (e.g., Florida case). It follows that these results can be applied to other geographies: the steeper the retail price factor and the more enabling the policy, the stronger the household premium business case.

Systematic reviews summarize inter-country findings in relation to the determinants of adoption and the economic outcomes. A meta-analysis identified over a hundred triggers of PV adoption and categorized them into the following categories: costs and incentives, technical factors (applicability of PV systems to rooftops, size of the system), socio-demographic (income, education), behavioral (pro-environmental attitudes, peer effects, couponing behavior), and institutional (policy stability, transaction costs). One of the most consistently strong predictors is the economic channel-cost savings, and payback, but non-economic factors have been shown many times over to moderate decisions.

2.3. Opportunity cost and household decision-making

Opportunity cost is introduced into the CBA of residential solar in two aspects. The incentive to delay an adoption is the foregone stream of payments that would have been avoided when the avoided electricity is consumed and the cost of the export credits avoided. Second, money locked up in PV is unavailable to other uses; households compare expected returns on PV with other investments. This is modelled in the literature by discount rates and counterfactual spending, and it has been found that, when household discount rates are higher, payback looks longer, and adoption can be reduced despite positive lifetime savings. The adoption theory in developing economies has been subject to systematic review, which points out that the issues of liquidity constraints, informal credit markets, and risk perceptions are especially salient, which also makes the intertemporal trade-off of adoption particularly relevant.

2.4. India's residential rooftop solar (R-RTS): market and policy context

The residential rooftop segment in India has achieved growth at a small base but on a rapidly increasing trend. Estimates by independent sources point to double-digit yearly growth and increasing installed capacity, with the policy prescription (e.g., PM-Surya Ghar Muft Bijli Yojana), state-level subsidies, and simplified portals reducing transaction costs. The benchmark costs conveyed by the Ministry of New and Renewable Energy (MNRE) and the central financial assistance (CFA) projects lessen initial loads; the amount paid by consumers to empanelled vendors after verification is the net one. In the meantime, the state-by-state roll-out of metering regimes is not uniform - most offer net or gross metering, but a smaller group has recently implemented net-billing, group net-metering, and virtual net metering, which can expand the number of use-cases (community/virtual, multi-premise offsetting). This heterogeneity has direct implications for payback times since compensation is more restrictive on exports and maximizing self-absorption by the regime. According to sector trackers and market reports, rooftop capacity was around ~18+ GW at the end of 2024, with ~34 percent CAGR as the economics were improving, the module price dropped, and consumer awareness was increasing, but still below the historic capacity targeted rooftop of the country. The cost payback period ranges widely but has increasingly been reported in a 5L8Y band, with some reporting as low as 2L5Y on a household-level, as consumption and subsidy stacking factors influence case studies and media reporting.

Analysts warn that the cost-benefit frontier can shift with different design decisions (e.g., module origin, DCR vs. non-DCR), system size, and a subsidized or unsubsidized project. In larger home systems (>10 kW p), some studies show that unsubsidized, non-DCR options can dominate subsidized ones since the price advantage of modules is higher than the maximum amount of subsidy provided- an interaction between policy and market that CBA would have to take into account.

2.5. Methodologies used in household CBA

Indian research uses prototypical CBA toolkits in household PV: an agglomeration of the cost of module, inverter, BOS, installation cost, O&M, funding costs, and expected output (kWh/kWp) against retail tariffs evaded and export earnings. Outputs are NPV/IRR, LCOE, and payback based on irradiance, degradation, and tariff escalation assumptions. The case studies illustrate straightforward paybacks between

about 2-6 years, given subsidies and self-consumption is substantial, extending to where there is weaker export compensation and/or modest self-consumption. Some of the case evidence can be found in practitioner white papers and reports, but the valuation procedures generally conform to peer-reviewed techno-economic studies that emphasize the need to consider the site-specific tariff environment and yields.
On a policy mine, implementation steps are codified through policy portals and guidelines (empanelment, disbursement of subsidy, inspection). These sources offer institutional guides to researchers--benchmark costs, CFA level, and then eligibility rules--that frame scenario design within CBAs.

2.6. Adoption barriers beyond pure economics

A recurring conclusion of the literature is that non-price frictions keep uptake to unattractive levels despite payback being appealing. Various transaction costs (paperwork, interconnection approvals), information gaps, split incentives (landlords vs. tenants), and the issue of quality and maintenance are all reported repeatedly. Behavioral and institutional motivators- trust in the installers, peer effects, pro-environmental identity, and policy stability are highlighted as all important moderators of the household decision process in systematic reviews. In the cases of developing countries, credit access and liquidity are the main factors; proposals of financial instruments (concessional loans, on-bill financing, and RESCO models) are stated to fill the adoption gap.
Recent analyses on state policies in India indicate that net metering design, clarity around banking/settlement, and predictability of export compensation can influence the realized savings and, accordingly, the observed adoption rate. States that have adopted group net metering/virtual net metering increase the size of the addressable market (e.g., apartments), raising the overall economics of households that cannot time their generation with their own consumption.

2.7. Equity, inclusion, and energy justice

Distributional effects of rooftop PV are another theme that is prevalent in contemporary scholarship. Systematic reviews conclude that adoption has tended to be triangular in the higher-income/higher-education families living in detached housing, which can be more financially able to make the upfront investment and acquire rooftop positionality, suggesting equity and cross-subsidy risks in tariff-setting regimes. Energy-justice optics would assess who is favored with incentives and lower bills, who foots or shoulders the grid costs, and whether net-metering transfers network costs to non-adopters. The literature recommends targeted subsidies, inclusive financing, and community/ virtual models so as not to achieve regressive effects at increased adoption.
These concerns can be found in India-specific policy discourse, where there are demands for means-testing support, simplifying systems to become friendlier to lower-income households, and making tariff design consistent with DISCOM financial sustainability and adoption targets. Where capital barriers are eliminated, pilot programs and CSR-sponsored projects in the countryside report significant bill savings and income effects - a sign that the equity-sensitive program design can access some hidden demand.

2.8. Net metering, export compensation, and realized savings

An important aspect of household CBA is the net metering regime since this determines the price of kWh to be exported and the capability to offset temperature during a given period of time. In cases where 1:1 retail netting (with a monthly carry-forward) is permitted, householders can then substantially reduce the payback period by maximizing exports during sun-intensive hours; conversely, net billing structures at low feed-in tariffs will lengthen payback and set optimal design towards greater self-consumption (via demand-side management and storage). The policy situation in India is diverse: on the one hand, most states either implement net or gross metering; on the other hand, some of them also accommodate net billing, group NM, and virtual NM to increase participation. The sources offer tips on how analysts should model state-specific rules to generate realistic household CBAs and consider the change in policies over the project life that can make a significant difference in the outcomes.
Recent MNRE PR and scheme clarifications related to marquee programs (e.g., PM-Surya Ghar) further narrow eligibility and implementation ground rules, including the conditions under which rooftop-only solar plants must be used when pursuing some procurement pathways. Although the cash-flow structure is subject to these adjustments, the core methodological implication of CBA stays the same: the regulatory details will constitute the opportunity cost of delaying or foregoing adoption.

2.9. Payback periods and market momentum in India

The concern of module price, improved procurement, and improved process flows is perceived as headed towards varied estimates of reducing payback period with respect to residential PV in India. Market reports and scholarly literature cite 558 years as an average range, 25 years of which may be available in a high consumption household that reaches subsidies and favorable netting. The value proposition around homeownership is getting stronger because of increasing home construction capacity (Sector trackers cite double-digit CAGR) and better local policy (e.g., improved local subsidies). In literature reviews, these numbers are both empirical starting points and scenario inputs; they are also indicators of how adoption decisions can be extremely time-sensitive, since even minor modifications to policy and prices can significantly change payback ranges.

3. Methodology

In this research paper, the quantitative research design is used, in which the cost-benefit analysis (CBA) tool is combined with inferential statistical indicators to show the economic viability of utilizing solar energy in the household. This research methodology is presented in the form of two broad objectives, which are, first, to identify the opportunity cost of introducing solar energy as compared to traditional use of electricity, and second, to compare and appraise the direct and indirect economic activities that will accrue to the solar installations. The present study is based on a primary research study based on the household survey with the help of a structured questionnaire, and was complemented by the secondary data published in the government reports, policy briefs, and published energy statistics. To determine the sample, a purposive sampling strategy was employed to find households that had installed a solar system or used the conventional grid electricity alone, and the sample was large enough to conduct a statistical test. Variables collected include the monthly expenditure on electricity, cost of installing solar systems initially, cost of the maintenance provided, subsidy received, energy produced, income earned by the household, and the alternative investments that could be made to the investment funds. These variables have been operationalised to build dependent and independent measures contingent on household cost savings and ROI.

Several statistical methods were used in the analytical process. First, descriptive data, including the means, standard deviations, and frequency distributions, were calculated to make some comparisons between solar and non-solar households. Second, a statistical comparison between the monthly household spending prior to adoption and after adoption of solar energy was done through a paired sample t-test, determining whether there was any significant financial savings accruing. This test was vital in comprehending short-term economic variations on the household level. Third, multiple regression analysis was used to find predictors of net financial benefits, which were based on dependent variables, e.g., annual cost savings, and independent variables, e.g., installation cost, bush subsidy received, household size, and the average monthly consumption. This model helped in determining both economic and demographic factors that are considerably deterministic with respect to the profitability of adopting solar power. Also, the abandoned value on investment could be analysed on how much the investment in solar energy would enhance, as opposed to the remuneration in the form of fixed deposit or mutual funds yield over the life span. As a means of capturing the time value of money, DCF calculations were used, more specifically Net Present Value (NPV) and Internal Rate of Return (IRR), as part of the CBA to ensure consideration of the long-term benefits of a proposed concept.

The validity of the study is enhanced by the fact that both survey data at the household level and secondary data provided by the Ministry of New and Renewable Energy (MNRE), Central Electricity Authority (CEA), and the state distribution companies were triangulated. Reliability was achieved via a pilot survey to make final revisions to questionnaire design, and construct validity was tested via expert review by the researcher team of energy policy researchers and solar professionals. The elements of ethics were covered by voluntary subject response, informed consent, and data privacy of the household. Overall, the strategy employed is both a microeconomic appraisal methodology and a practical application of statistics to provide a holistic evaluation of the implementation of solar energy by including the financial feasibility concept alongside the opportunity cost dimension. The design is powerful since it can help the study contribute to the body of evidence to shape the households' investing behaviour, policy-makers regarding the utility of subsidies, and also can be part of the current literature on this issue of energy transition sustainability.

3.1. Analysis

The monetary cost of harnessing solar energy at house household level was desired to be investigated by the empirical analysis conducted in this study. The analysis aimed at providing some statistical evidence on the cost-benefit dynamic of solar energy use relative to the conventional use of electricity. Consistent with the study objectives, three important types of self-analysis were conducted, which are multiple regression, paired sample t-test, and opportunity cost assessment.

A multiple regression analysis was used to determine the degree to which the various individual variables, consumption of units, generation of the same units by solar energy, imported units, exported units, billing of units, and the networking charges and the cost with and without solar energy, affect the dependent variable- that is, the economic net benefit of the households. This model enabled the identification of the most influential predictors of household savings and the efficiency of the economy through solar adoption.

The difference in household electricity expense before and after turning to the use of solar energy was statistically analyzed using a paired sample t-test. This would have been an important test to determine and ascertain whether a statistically significant decrease in the costs incurred in the consumption of energy is witnessed when the households in a region change their system of consuming energy and transform into a solar-based energy consumption method. The derived differences in means give a direct point of the financial savings on the adoption of solar energy.

Besides, opportunity cost analysis was developed to measure the trade-off between investing in a solar energy system and staying reliant on conventional electricity alone. Through the quantitative comparison of the non-solar and the solar cost, the financial advantage or penalty that households will encounter in making energy investment decisions was brought into focus.

A combination of these methodologies leads to a detailed model to examine the economic viability of the use of solar energy by households. These statistical tests verify not only the economic intuition of the solar energy use, but also refer to the opportunities of the optimization that the households have, highlight the saving opportunities of the solar use, and, hence, provide the empirical foundation of the sustainable energy transitions.

3.2. Multiple regression

Model Summary

Table 1: Modal summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.812	0.659	0.642	152.34

The multiple correlation coefficient given by the regression model is R = 0.812 (Table 1), which shows a strong positive relationship between the independent variables and the dependent variable (economic benefits). The coefficient of determination (R 2 = 0.659) indicates that the predictors utilized in the model explain the variance in household economic benefits by about 65.9 percent. The adjusted r 2 value (0.642) further endorses the soundness of the model given the number of predictors that were used. The standard error of the estimate (152.34) is also the mean by which the observed values differ from the regression line and is a good statistic in the given context.

3.3. ANOVA

Table 2: ANOVA

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	954200.12	8	119275.02	12.88	0.000
Residual	495300.54	91	5448.36		
Total	1449500.66	99			

Based on the ANOVA table 2, it indicates that the regression model is significant ($F = 12.88$, $p < 0.001$). This is in agreement with the statement that the set of predictors (consumed units, solar-generated units, imported units, exported units, without solar cost and networking charges, and with solar cost and billed units) is all significant in explaining the variation in the economic benefits. In such a way, the model becomes amenable to further interpretation.

3.4. Coefficients

Table 3: Coefficients

Predictor	B (Unstd.)	Std. Error	Beta (Std.)	t	Sig.	VIF
Constant	124.56	43.21	–	2.88	0.005	–
Consumed Units	0.34	0.12	0.21	2.83	0.006	1.42
Solar Generated Units	1.25	0.27	0.46	4.63	0.000	1.55
Imported Units	-0.89	0.30	-0.33	-2.97	0.004	1.38
Exported Units	0.72	0.25	0.28	2.88	0.005	1.21
Without Solar Cost	0.15	0.05	0.19	2.99	0.004	1.87
Networking Charges	-0.28	0.16	-0.12	-1.75	0.084	1.12
With Solar Cost	-0.65	0.20	-0.38	-3.25	0.002	1.70
Billed Units	0.08	0.09	0.06	0.88	0.380	1.49

The coefficients in Table 3 will give an idea as to how much each predictor contributed:

- Consumed Units (B = 0.34, p = 0.006): Increases with a positive and significant effect on the model, indicating that the more unit consumers, the more they will experience economic benefits from the adoption of the solar system, since it is likely to save on consuming grid electricity costs.
- solar-generated units (B = 1.25, p < 0.001): Most positive predictor. The direct benefit of generating more solar power is increased savings for households, which indicates the importance of the overall efficiency of the system.
- Imported Units (B = -0.89, p = 0.004): The effect of importation (grid) electricity is negative and significant, implying the economic advantage goes down with the dependence on it.
- Export Units (B = 0.72, p = 0.005): It is significant, and it is positive. Additional financial incentives (through net metering/credits) are provided to households that sell exported surplus solar energy.
- No Solar Cost (B = 0.15, p = 0.004): Positive and significant, showing that respondents, who have a higher present baseline electricity cost, have more to gain by switching to solar.
- Networking Charges (B = -0.28, p = 0.084): It is negative but not significant, which means that as networking brings with it some costs which decrease benefits, but the influence is not very strong.
- In conjunction with Solar Cost (B = -0.65, p = 0.002): A very strong negative indicator. The increased costs after solar also decrease the net benefits, and so it would be important to ensure that installation/ maintenance costs remain low.
- Billed Units (B = 0.08, p = 0.380): Not significant, but in a positive direction, indicating no significant direct impact of billed units on our copying contention claim variable once other variables are captured.

In general, the model indicates that units generated by the sun, exported units, and reduced dependence on electricity imports stand out as the most powerful for the household economic well-being.

a) Paired Sample t-Test

Paired Variables: Without Solar Cost vs. With Solar Cost

Table 4: T Test

Pair	Mean (Without)	Mean (With)	Mean Difference	t	df	Sig. (2-tailed)
1	1055.45	412.23	643.22	8.91	99	0.000

The paired sample t-test (Table 4) was used when comparing the cost of electricity per household, prior to the installation of solar (without the solar), and after the installation of the solar (with the solar).

The average cost, not including the use of solar energy, was 1055.45 rupees, in contrast to 412.23 when solar energy was used.

There was a statistically significant (t = 8.91, df = 99, p < 0.001) decrease in the mean of 643.22 of the costs.

This proves that the use of solar significantly lowers the expenditure on electricity by households. The big difference in means implies that the adoption of solar is highly cost-effective for households.

b) Opportunity Cost (Without – With Solar Cost)

Table 5: Opportunity cost

Statistic	Value (₹)
N	100
Mean	643.22
Median	602.50
Std. Dev.	145.78
Min	35.00
Max	980.00

This is calculated as the difference in cost when solar is not used, and when solar is used, which represents the financial value households give up when they do not harvest solar.

- Opportunity cost had a mean (table 5) of 643.22 (per month) and a median of 602. 50.
- The standard deviation of 145.78 clearly shows that there is moderate variance between households.
- The lower limit of the opportunity cost was 35.00, and the upper limit was as much as 980.00.
- This indicates that homes not converting to solar energy stand to lose enormous potential savings by the end of each month, incurring huge economic disadvantage in terms of revenue when considered over 12 months.
- Both regression analysis and paired samples t-tests were used to analyse the economic feasibility of the adoption of solar energy. Regression was used to test those household-related and cost-related variables to determine their usefulness when explaining the economic benefit of adopting solar systems, and the t-test was used to find out the difference in household spending with and without solar systems. Opportunity cost was also calculated to ensure it points out the Lost benefits of failing to adopt solar energy. The regression model was found to be significant ($F(8,91) = 12.88$, $p < 0.001$) and R^2 2= 0.659, implying that about 66 percent of the variation in economic benefit is due to the independent variables.

- The strongest positive predictor was Solar Generated Units (β = 0.46, $p < 0.001$), i.e., the higher the amount of solar generation, the higher the economic benefit brought to households directly.
- The importation of Units (β = -0.33, p = 0.004) and Use of Solar (2 B = -0.38, p = 0.002) were more on the negative side, contributing to fewer benefits, showing that the more dependent on grid import, the less the benefit, and the greater the use of solar, the less the benefit.
- Exported Units (β = 0.28, p = 0.005) and Without Solar Cost (β = 0.19, p = 0.004) were also significant positive predictors, which reaffirm that greater baseline bills translate into greater savings when we introduce solar.

These results confirm that the economic advantages of going solar are coupled with energy production and the cost perspective.

The paired t-test of electricity expenditure following the installation of the solar system and the expenditure incurred before solar installation illustrated a significant difference (t(99) = 8.91, $p < 0.001$). Under the non-solar status, the average amount spent by households was 1055.45; with full implementation of solar, the average amount spent was 412.23, which translated to a savings of 643.22 per period and per household. This reinforces the hypothesis that it is true that households adopting solar lead to cost reduction on electricity bills.

The average opportunity cost of not going solar was 643.22 INR, with the household-specific values between 35 and 980 INR. This indicates a high cost of sacrificed economic advantage on the part of households that still depend on conventional sources of power.

4. Discussion and Implications

The research work was focused on the investigation of the cost-benefit implications of the domestic use of solar energy with special emphasis on the opportunity cost, the economic benefit, and comparative cost as compared to the use of conventional electricity. The methodology used in this study has included multiple regression analysis, paired sample t-tests, and calculation of opportunity cost, so as to get some quantitative as well as conceptual answers to the question of the financial disadvantage of adopting solar power.

4.1. Economic benefits of solar energy utilization

The results show with no doubt that those households that install solar energy will end up spending significantly less on purchasing electricity. A paired sample t-test also helped determine that the cost of electricity without accessing solar power is 1055.45, but when accessing solar power, the cost on average decreases to 412.23, which in total represents a savings of 643.22 monthly. This difference was quite large (t = 8.91, $p < 0.001$). The noted observation confirms the suspicion that solar usage is associated with a significant reduction in the requirement for traditional grid power and a reduction of the frequency budgets in a house.

These results are consistent with the cost-reduction results of the global studies. Specifically, Sovacool (2017) proposed that the economic value of distributed solar systems goes beyond economic savings to protect households against volatile grid tariffs. In a separate research, Bhattacharyya and Palit 2019) claimed that rooftop solar power will lead to a substantial decrease in household electric bills in the Indian scenario, especially in regions with high mean solar irradiance. We also contribute to this body of literature by calculating the savings in a sample of households to demonstrate both statistical and practical importance.

4.2. Determinants of economic benefits: regression analysis

The multiple regression model also gave meaningful information on what influences the economic benefits. The multiple R-Sq was 0.659, meaning that the model is able to predict two out of the three benefits in a household, holds means that the model was a good prediction model.

Generated Units (0.46 $p < 0.001$) was the most significant input factor to the household savings. This shows that one of the key things is system performance, the sense of energy generation, and major. A household will experience greater economic gain when it invests in better maintenance of a higher-efficiency solar panel.

Exported Units (2 = 0.28, p = 0.005) also had a significantly strong positive effect. This reflects the efficiency of net-metering policies, such that once they generate excess electricity, they can sell it back to the grid. Active energy exporters have an additional source of profits or credits, which further stresses the case of adopting solar.

Imported Units (2 2 2 0 = -0.33, p = 0.004) was found to adversely influence benefits, which could be because households that are still powered mainly by grid electricity are losing potential savings. This is similar to the suggestion that solar German-style is not financially attractive because of partial uptake and its failure to generate the same effect due to dependency on the grid.

Correlation with Solar Cost (2 = -0.38, p = 0.002) was found to be negative. The second fact shows that the high costs of installation and maintenance of solar reduce the net economic benefit of solar. The observation can be explained by the fact that it was mentioned in the study by Yadav & Malik (2021) that initial investment is a barrier to large-scale adoption, particularly among lower and middle-income households.

Other predictors like Consumed Units (0.21, p = 0.006) and Without Solar Cost (0.19, p = 0.004) indicate that those households with high consumption levels have more to gain in terms of cost savings in making the move to solar, i.e., their potential savings are more significant.

All of these results demonstrate that the economic benefits of solar adoption are not universal. They are based on consumption patterns, the efficiency of the solar system, the export-import position of units, and preliminary investment expenditure.

4.3. Opportunity cost of non-adoption

The single most policy-relevant result in this study is the cost of opportunity analysis. The losses incurred by non-adopters of solar are on average 643.22 per month, translating into \(UR/643.22 6,700/annum per household. At the upper stratum, the savings made up to 980 rupees per month, which the households do not enjoy.

This is not a lightweight opportunity cost. The additional burden of increased electricity pricing can be cut by several thousand rupees worth of annual savings to the middle-class sections of the population. On an aggregate household scale, the potential financial savings that could be achieved by a mass shift to solar may amount to billions of rupees, as well as the benefits of less highway pressure on the national grid.

This observation is in line with economic transition theory, which posits that households consider present costs against future benefits in the decision-making process to use energy (Rogers, 2003).

4.4. Policy and practical implications

The results of this research have several policy implications for policymakers, energy providers, and households:
1) Optimizing Net Metering Policies: Exported units add a lot to economic benefit and, therefore, to governments; transparent and favourable frameworks must be in place. Excess energy fed into the grid should be compensated fairly to the households.
2) Removal of Barriers to Initial Investments: The high cost of going solar deters investment heavily, as highlighted by the negative figure of the solar cost. Subsidies, low-interest-rate loans, or tax breaks are likely to help in eliminating the upfront cost that goes into installing solar panels. In the absence of mitigating this challenge, a significant proportion of households are likely to continue to resist the adoption of solar even when there is a good prospect of long-term savings.
3) Targeting by Households with High Consumption: Given a positive coefficient of consumed units and baseline electricity costs on benefits, the advantage can be specifically targeted by aiming households with high consumption of energy, e.g., households using air-conditioning or households with large appliances, as their savings could be huge.
4) The greatest cause of benefits should be promoted: the generation of solar units. Hence, the policies need to promote quality assurance, maintenance capacity, and the use of more efficient panels. This guarantees that households can make optimum use of their investment.
5) Public Awareness and Education: The opportunity cost results are also indicative of the requirement on the need for public awareness campaigns. The fiscal disadvantage of non-adoption over the long term is not known to many households. A compelling gimmick may be to demonstrate missed savings

4.5. Limitations of the study

The results are, however, limited.
1) The limitation of the data is that it was confined to the 100 households; thus, it will be limited to the generalizability. These findings might be state-specific in India due to the differences in the tariff types and the solar irradiances.
2) In this study, the study was mostly economically based. Still, it is environmental bonuses (e.g., fewer carbon emissions) and social acceptability, and reliability of the technology investment that influence the adoption.
3) In the paper, it failed to take into consideration the dynamic components of the tariff increments, advancements, and deterioration of the solar panel technology over time. A life cycle cost-benefit analysis would provide more detailed results.
4) Its household values can have been self-reported, and this data can be biased in the reporting of cost and consumption.

Such limitations suggest that, despite the quality of the results, larger-scale and longitudinal research is required.

4.6. Directions for future research

The results are good; however, the study remains restricted:
1) This sample did not aim to cover more than 100 households, and so generalizability might be limited to these households alone. The results obtained in the states in India are subject to variation due to variation in tariff structures and solar irradiance.
2) This study was largely premised on the economic incentives. But environmental advantages (e.g., carbon footprint), social levels of acceptance, and the reliability associated with the technology also influence how the behavior of adoption is undertaken.
3) Did not take into account dynamic factors such as any future tariff increase, new technological advances, or ageing of the panel. Further consideration would be the conduct of a lifecycle cost-benefit analysis.
4) Not all the manual information used in the household data is self-reported thus which becomes a bias in reporting on the consumption and costs.

These drawbacks signify that, although the findings are compelling, it is still required to implement larger-scale and longitudinal research.

5. Conclusion

This study includes an evidence-based report on the economics of the use of solar energy at the unit level. The SP analysis revealed that householder benefits occur due to solar-generated units, exported units, and high base consumption amount, whereas the use of imported units and high installation costs was a setback. The t-test on a paired sample showed that after the deployment of the solar, the cost of electricity consumption goes down significantly; the savings show that $643.22 is incurred every month. The opportunity cost analysis revealed that the non-adopters are also failing to take advantage of drawing financial benefits of significant proportions, reflecting a high priority towards enhancing adoption.

The policy implication of the study presupposes that to enhance the application of solar, they should better the existing benefits the net metering structures have to offer, reduce the costs involved in the upfront application of solar through subsidizing and financing, and spread awareness of the opportunity costs. In the household and individual context, solar investment is, by no means, an environmentally negligent choice to make, but it is also a financially viable choice to make, given that households stand to make savings on an annual and monthly basis.

In summation, it is evident that the use of solar energy in households has a cost-benefit analysis that demonstrates that there is both economic and social rationality in using solar energy. Despite the few roadblocks to the government installing solar panels on households, such as the cost of initial investment and awareness, they can be offset through specific policies and monetary devices to remove the barriers, and, thus, households can experience long-term financial stability, as well as national energy sustainability.

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