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Solar Villages: Evaluating the Economic Benefits of China's Rural Electrification Programs

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ABSTRACT

Rural solar-based electrification has become an important instrument for expanding energy access while promoting socio-economic development in rural areas. This study aims to examine the impact of rural solar electrification programs in China on household income, education, and public health. The study employs a quantitative approach with a quasi-experimental design, combining Difference-in-Differences (DiD) and Propensity Score Matching (PSM) to compare socio-economic changes between areas receiving electrification interventions and comparable control areas with similar initial characteristics. The findings indicate that rural electrification has a positive effect on household income, particularly non-farm income, and contributes to improvements in educational attainment and health outcomes. More specifically, electrification is associated with increased years of schooling, higher school participation, and longer study time among children, while also reducing the incidence of respiratory illness and improving households' perceived health status. These findings suggest that rural solar electrification serves not only as a means of providing energy access but also as a broader development instrument that expands economic opportunities, strengthens human capital, and enhances rural welfare. Therefore, rural electrification policies should be integrated with local economic development, education, and health programs to maximize their long-term, sustainable benefits.

1. INTRODUCTION

Rural electrification has long been regarded as an important component of inclusive development, particularly in regions where limited access to modern energy continues to constrain everyday life and local economic activity. In rural areas, electricity is not merely a technical utility; it is closely connected to how households work, study, access information, and maintain their health. Where electricity remains limited or unreliable, households often face lower productivity, fewer opportunities for non-farm employment, reduced study time for children, and poorer living conditions overall. For this reason, rural electrification should be understood not simply as an infrastructure policy, but as a broader development intervention with potential implications for multiple dimensions of welfare.

A growing body of literature has shown that the benefits of rural electrification extend well beyond energy access itself. In economic terms, electrification may reduce dependence on inefficient traditional fuels, extend productive hours, and create opportunities for income diversification, especially through non-farm activities. Gashaye et al. (2025), for example, find that electrification in Ethiopia contributes to lower household energy expenditures and improved economic opportunities. In the field of education, electricity allows for more stable lighting, access to learning devices, and a more supportive home learning environment, all of which may improve school participation and study time. Evidence from Bangladesh likewise suggests that electrification is associated with better household social conditions and improved quality of life, including through education-related channels (Sarkar et al., 2025). From a health perspective, the shift from traditional fuels to cleaner energy sources may reduce indoor air pollution and, consequently, lower the risk of respiratory illness in rural communities (Ali et al., 2024). Taken together, these findings suggest that electrification can influence household welfare through several interconnected pathways, rather than through a single economic channel alone.

In China, the issue of rural electrification is closely tied to long-standing regional inequalities, especially between urban centres and remote rural areas where access to basic infrastructure has historically lagged behind. In response to these disparities, the Chinese government introduced a series of rural electrification initiatives based on renewable energy technologies. Two of the most prominent were the Township Electrification Program (TEP) and the Village Electrification Program (VEP). The TEP, launched in 2001, was among the earliest large-scale efforts to expand electricity access in western China through renewable sources such as

solar, wind, and small hydropower. This initiative was later followed by the VEP in 2005, which targeted thousands of villages and millions of residents, particularly in areas where extending the conventional electricity grid was economically difficult. These programs were intended not only to improve access to electricity but also to support broader national objectives, including poverty reduction, regional development, and the transition toward cleaner energy systems (Zhang & He, 2013).

Despite the scale and policy significance of these programs, the socio-economic effects of rural electrification in China have not yet been fully established in the literature. Much of the existing discussion has focused on technical implementation, program coverage, and the role of renewable energy in rural energy policy. By contrast, fewer studies have examined whether and to what extent electrification has translated into measurable improvements in household welfare. Several studies do point to positive economic effects. Zhang and Kumar (2011), for instance, examine the impact of rural electrification in western China, while Liu et al. (2016) explore the relationship between solar electrification and household income. Other studies also suggest that rural photovoltaic programs may contribute to poverty alleviation and regional development (Zhang et al., 2020). However, much of this literature remains relatively narrow in scope, as it tends to focus primarily on income-related outcomes or on poverty reduction, without considering how electrification may simultaneously affect other dimensions of welfare.

This is where an important gap becomes visible. Rural electrification is unlikely to influence only one aspect of household life. Increased income may improve a household's ability to finance education and healthcare; better educational outcomes may strengthen human capital and future productivity; and improved health conditions may reduce economic burdens while enhancing labour capacity. In other words, the effects of electrification are likely to be cumulative and interconnected. Yet many previous studies still assess its impact in a fragmented way, often focusing on a single indicator or relying on aggregate data that make it difficult to capture welfare changes at the local level. As a result, the broader developmental role of rural solar electrification in China remains insufficiently understood.

Against this background, this study identifies two main research gaps. First, there is still limited research that evaluates rural solar electrification programs in China by examining household income, education, and health within one integrated analytical framework. Existing studies tend to focus on a single outcome, while the wider social benefits of electrification are

often treated as secondary or indirect. Second, there remains a need for stronger empirical evaluation of how far electrification is associated with observable welfare improvements, particularly through a quasi-experimental approach that allows comparison between program areas and comparable non-program areas with similar initial characteristics. This matters because the success of rural electrification should not be judged solely by the number of villages connected to electricity, but also by whether such interventions actually improve the socio-economic conditions of rural communities.

Based on these gaps, the present study offers novelty at two levels. Substantively, it examines rural solar electrification not through a single welfare outcome, but through three interrelated dimensions of rural well-being: household income, educational attainment, and public health. This allows the study to capture the broader developmental implications of electrification rather than reducing its impact to a single economic measure. Methodologically, the study applies a quasi-experimental framework by combining Difference-in-Differences (DiD) and Propensity Score Matching (PSM) in order to compare socio-economic changes between electrified areas and comparable control areas with similar pre-intervention characteristics. In this way, the study seeks to provide a more systematic assessment of the relationship between rural solar electrification and welfare change in China.

Accordingly, the main contribution of this study lies in its effort to evaluate rural solar electrification in China in a more comprehensive manner by linking income, education, and health as interconnected dimensions of welfare. Unlike earlier studies that are either technically oriented or limited to one specific outcome, this study treats electrification as a broader development intervention whose effects extend across several aspects of household well-being. By doing so, it aims to contribute not only to the literature on rural electrification but also to the wider discussion on how renewable energy policies can support rural development in a more integrated and socially meaningful way.

In light of the above, this study aims to examine the impact of rural solar electrification programs in China on three key dimensions of welfare, namely household income, education, and public health. More specifically, it asks the following question: to what extent do rural solar electrification programs in China contribute to higher household income, improved educational outcomes, and better health conditions in rural program areas? By addressing this question, the study is expected to provide a more grounded understanding of the socio-economic implications

of rural solar electrification and to offer empirical support for more integrated rural energy and development policies.

2. LITERATURE REVIEW

Rural electrification has long been discussed in development studies as more than a matter of infrastructure provision. In rural settings, access to electricity may alter the way households work, allocate time, invest in education, and manage daily health-related needs. For this reason, electrification is often approached not only as an energy intervention, but also as a broader development strategy with potential implications for household welfare. At the same time, the literature shows that these effects are neither uniform nor automatic. Their scale and direction depend on local economic conditions, the availability of complementary infrastructure, and the extent to which electricity can be translated into productive and social uses. The existing literature therefore suggests that the impact of rural electrification should be understood through several interrelated dimensions rather than through a single economic indicator alone.

In the broader international literature, electrification has been associated with a range of socio-economic improvements. Studies from developing countries indicate that electricity access may expand non-farm opportunities, reduce dependence on traditional energy sources, improve the home environment for learning, and support healthier living conditions. Yet the evidence also remains uneven. In some contexts, electrification generates clear welfare gains, while in others the effects are more gradual and depend on whether households have the means to use electricity productively. This mixed but generally supportive literature provides an important foundation for understanding why electrification may influence household income, educational outcomes, and health, which together form the core welfare dimensions examined in this study.

Rural Electrification and Household Income

One of the most frequently discussed benefits of rural electrification is its potential contribution to household income. The underlying argument is relatively straightforward. Access to electricity can extend working hours beyond daylight, support the use of productive appliances and machinery, reduce time spent collecting or managing traditional fuels, and create new possibilities for small-scale business activity. In rural economies, these changes may be especially important because they allow households to diversify away from a narrow dependence

on agricultural income and participate more actively in non-farm employment and micro-enterprise activities.

This logic is consistent with a broader development perspective that views infrastructure as a productive input rather than merely a public service. Energy access can reduce transaction costs, improve labour productivity, and increase the efficiency of household and business activities. Munnell (1992) argues that infrastructure investment plays an important role in supporting productivity and economic performance, while Burke et al. (2017) show that electricity access can be closely linked to broader development outcomes in low-income settings. In the context of rural electrification, the implication is that access to reliable power may affect income not only by lowering energy-related constraints, but also by enabling households to engage in more diverse and higher-value economic activities.

Empirical evidence from several countries supports this expectation, although the strength of the effect varies across settings. Dinkelman (2011), for example, finds that rural electrification in South Africa increased female employment, partly by reducing the time burden of domestic work and enabling greater participation in market activities. Khandker et al. (2012) and Grogan and Sadanand (2013) similarly show that electrification in Bangladesh and Nicaragua was associated with improvements in household income and employment opportunities. In Ethiopia, Bernard and Torero (2015) and Gashaye et al. (2025) also point to the economic benefits of improved electricity access, particularly through lower energy expenditures and expanded opportunities for productive activity.

At the same time, the literature also suggests that income gains from electrification are not always immediate or uniform. Lee et al. (2020) and Burlig and Preonas (2021) show that electrification does not necessarily generate large short-term economic returns where households face wider structural constraints, such as limited access to capital, weak market integration, or low demand for electricity-intensive production. Van de Walle et al. (2017) likewise suggest that some benefits of electrification may emerge only gradually over time. These findings are important because they caution against assuming that electrification automatically transforms rural economies. Instead, the income effect of electrification appears to depend on whether households are able to convert electricity access into productive use.

In China, this question is particularly relevant because rural electrification programs were designed not only to improve energy access, but also to support poverty reduction and regional

development. Zhang and Kumar (2011) report that rural electrification in western China contributed to better local economic outcomes, while Liu et al. (2016) find positive income effects associated with solar electrification. Other studies also suggest that rural photovoltaic programs can help reduce poverty and expand economic opportunities in disadvantaged regions (Zhang et al., 2020; Peng et al., 2022; Wang et al., 2023). Even so, much of this literature remains focused primarily on income or poverty indicators, without fully considering how economic gains interact with other dimensions of household welfare.

Taken together, the existing literature provides a strong basis for expecting that rural solar electrification can improve household income in rural China, particularly by easing energy constraints and supporting greater participation in productive and non-farm activities. In light of this reasoning, the first hypothesis of this study is formulated as follows:

H1: Rural solar electrification has a positive effect on household income in rural China.

Rural Electrification, Education, and Human Capital

A second important channel through which electrification may affect welfare is education. In rural households, access to electricity can improve the conditions under which children study, especially by providing better lighting after dark, enabling the use of educational devices, and increasing access to information. These changes may seem simple, but they are potentially important in areas where children's study time is constrained by the absence of reliable lighting or by poor access to learning resources. Electrification may therefore contribute to educational outcomes not only by extending the hours available for study, but also by improving the overall quality of the home learning environment. Electrification is essential for digital education (Nandy & Majee, 2023).

From a human capital perspective, this relationship is highly relevant. Education is one of the key mechanisms through which rural households improve long-term welfare and future earning capacity. If electrification supports school participation, learning intensity, or educational attainment, then its impact extends beyond immediate energy access and enters the domain of intergenerational development. In this sense, the educational effect of electrification is not simply a secondary social benefit; it is part of the broader developmental value of rural infrastructure.

Previous studies provide support for this argument. Khandker et al. (2012) show that electrification in rural Bangladesh improved study time and was associated with better educational outcomes. Van de Walle et al. (2017) similarly find that electrification in rural India contributed to improvements in schooling and educational participation, even where the income effects were relatively modest in the short run. These findings suggest that education may be one of the domains in which the benefits of electrification become visible relatively early, particularly because better lighting and access to information affect daily study practices directly.

In the Chinese context, the link between electrification and education is also plausible for structural reasons. Rural communities in China have long faced disparities in educational access and quality compared with urban areas, especially in remote western provinces where infrastructure provision has historically lagged behind. In such contexts, electricity can reduce some of the practical barriers that limit children's ability to study at home and may help households access a wider range of educational resources. For villages that previously relied on weak or unstable energy sources, electrification can improve the basic conditions necessary for learning, including lighting, communication, and access to electronic devices. Even if the direct literature on solar electrification and education in China remains more limited than the literature on income, the theoretical and empirical logic points in the same direction: better access to electricity is likely to support stronger educational outcomes over time.

This argument is also consistent with the broader framing of rural electrification as an investment in human development. If electrification reduces time constraints, improves study conditions, and supports school participation, then its educational effects should be considered a central part of its welfare impact rather than a peripheral by-product. On this basis, the second hypothesis of the study is proposed as follows:

H2: Rural solar electrification has a positive effect on educational outcomes in rural China.

Rural Electrification and Health Outcomes

The third welfare dimension examined in this study is health. Compared with the literature on income, the health effects of electrification are somewhat less frequently analysed in a direct and systematic way, yet the underlying mechanisms are highly relevant. Access to electricity may improve health both directly and indirectly. Directly, electrification can reduce reliance on kerosene, coal, or biomass for lighting and household energy use, thereby lowering exposure to

indoor smoke and harmful pollutants. Indirectly, electricity can improve food storage, support refrigeration for medicines and vaccines, facilitate access to cleaner water and sanitation practices, and strengthen the functioning of local health services.

These mechanisms are especially important in rural communities where public health infrastructure is limited and where traditional energy use remains common. In such settings, the health burden associated with indoor air pollution, smoke exposure, and energy poverty can be substantial. Ali et al. (2024) highlight the health implications of household energy choices, particularly in relation to respiratory outcomes linked to traditional fuels. From this perspective, a shift toward cleaner and more reliable electricity sources may generate meaningful health benefits by reducing environmental risks within the household and by improving access to basic health-supporting services.

The relevance of this channel becomes even clearer when electrification is linked to broader household welfare. Poor health imposes economic costs through medical spending, lost work capacity, and reduced school participation among children. By contrast, improved health conditions may ease these burdens and reinforce gains in both productivity and education. This means that health should not be treated as an isolated social outcome; it is part of the wider process through which electrification may reshape household welfare. In rural areas where access to formal healthcare is already uneven, even relatively modest improvements in household energy conditions may have important implications for well-being.

In China, this issue matters because many of the regions targeted by rural solar electrification programs are remote and historically underserved in terms of infrastructure and public services. Electrification in such settings may contribute to healthier living conditions by reducing dependence on polluting fuels and by improving the material conditions of everyday life. Although the Chinese literature has more often emphasized the economic and technical aspects of electrification programs, the broader welfare logic suggests that health improvements should also be expected where electricity access becomes more stable and reliable. On this basis, the third hypothesis of the study is formulated as follows:

H3: Rural solar electrification has a positive effect on health outcomes in rural China.

Research positioning

The literature reviewed above suggests that rural electrification may influence welfare through several connected pathways. It may expand income opportunities by supporting

productive and non-farm activities, improve educational outcomes by strengthening the home learning environment, and contribute to better health by reducing reliance on traditional fuels and improving everyday living conditions. However, these dimensions are often examined separately, while studies on China's rural solar electrification programs have tended to focus either on technical implementation or on a single welfare outcome at a time. This leaves an important gap in understanding the broader social effects of solar electrification in rural China.

The present study is positioned within this gap. Rather than treating electrification as a purely technical intervention, it examines rural solar electrification in China as a multidimensional development program whose effects may be observed across household income, education, and health simultaneously. In doing so, it connects the policy context of China's solar electrification initiatives with a welfare-oriented empirical framework that allows these outcomes to be assessed together. The hypotheses developed above provide the basis for the empirical analysis that follows.

3. METHODOLOGY

This study evaluates the socio-economic effects of China's rural solar electrification programs by combining village-level socio-economic indicators with program records and supplementary administrative and satellite-based data. The analysis focuses on the Township Electrification Program and the Village Electrification Program, which expanded electricity access in remote rural areas through solar-based and other off-grid systems in line with China's broader renewable energy strategy (Xie et al., 2011; Zhang & He, 2013). To capture welfare outcomes beyond electricity access itself, the study draws on socio-economic indicators from the National Bureau of Statistics of China, official electrification project records, DMSP-OLS and VIIRS night-time light data, Ministry of Education and Ministry of Health records, and supplementary information from the China Health and Nutrition Survey. These sources make it possible to examine whether electrification was associated with changes in household income, educational outcomes, and health outcomes across rural villages, while also accounting for baseline differences in remoteness, infrastructure, and village poverty conditions.

To estimate the welfare effects of electrification, the study employs a quasi-experimental strategy combining Difference-in-Differences (DiD) and Propensity Score Matching (PSM). The DiD model compares changes in income, education, and health outcomes between electrified and non-electrified villages over time, while village and year fixed effects are included to control

for time-invariant local characteristics and broader macro-level shocks. Because electrification was not randomly assigned, PSM is used to construct a more comparable control group on the basis of observable pre-treatment characteristics before the DiD estimation is performed. The analysis also considers post-electrification dynamics, since the benefits of electricity access may emerge gradually rather than immediately. This empirical strategy is consistent with the long-standing view that rural photovoltaic deployment in China should be evaluated not only as an infrastructure intervention, but also as a development strategy with implications for income, human capital, and welfare (Wallace & Tsuo, 1997).

Table 1. Variabel Definition

Variable	Definition / Measurement	Source
Household income	Annual average rural household income, measured in inflation-adjusted Chinese yuan (CNY). This variable captures the economic welfare dimension of electrification.	National Bureau of Statistics of China
Educational outcomes	Indicators of educational improvement in electrified villages, including school enrollment and related measures of educational participation used in the empirical analysis.	National Bureau of Statistics of China; Ministry of Education
Health outcomes	Health-related indicators used to capture changes in household and community well-being, including measures reported in administrative and survey-based sources.	Ministry of Health; China Health and Nutrition Survey
Electrification status	Binary indicator equal to 1 if a village received solar electrification under the Township Electrification Program or Village Electrification Program, and 0 otherwise.	Township Electrification Program and Village Electrification Program reports
Years since electrification	The number of years elapsed since a village received electrification is used to assess the dynamic effects of treatment over time.	Township Electrification Program and Village Electrification Program reports
Distance to urban center	Measure of village remoteness based on distance to the nearest urban or county center. Included as a control variable.	National Bureau of Statistics of China
Baseline infrastructure	Pre-electrification village infrastructure conditions, including the presence of basic public facilities and physical access indicators, where available.	National Bureau of Statistics of China; project records
Poverty index	Baseline indicator of village socio-economic disadvantage before electrification, used to control	National Bureau of Statistics of China

Variable	Definition / Measurement	Source
	for differences in initial development conditions.	

Source: Variable construction is based on the original dataset described in the study, which combines administrative statistics, electrification project records, and supplementary survey and satellite data. The program background and rural electrification context are informed by prior work on China's renewable energy and township electrification policies (Xie et al., 2011; Zhang & He, 2013; Wallace & Tsuo, 1997).

4. RESULT AND DISCUSSIONS

This section presents the empirical findings on the socio-economic effects of China's rural solar electrification programs across the three outcome domains established in the research framework: income, education, and health. In line with the empirical strategy outlined earlier, the effects are reported dynamically for one, three, and five years after village electrification. Across all three domains, the results point to a consistent pattern: the estimated effects are positive, statistically meaningful, and generally stronger over time. This temporal pattern is important because it suggests that the benefits of electrification were not limited to the initial moment of access, but accumulated as households gradually integrated electricity into productive activities, educational routines, and everyday domestic life.

Income Effects

The income results provide strong support for H1, indicating that rural solar electrification improved household income in treated villages. As reported in Table 1, total household income in electrified villages was approximately 5.0% higher than in comparable non-electrified villages one year after electrification, rising to 8.0% after three years and 10.0% after five years. These gains were driven primarily by non-farm income rather than farm income. Non-farm income increased by 8.2% in the first year, 12.4% after three years, and 15.3% after five years, whereas farm income did not show a statistically significant effect over the same period. This pattern suggests that electrification did not simply raise income in a general sense, but specifically expanded non-agricultural earning opportunities in rural areas.

Table 2. Impact on Income Outcomes (Regression Estimates)

Outcome	1-year effect (95% CI)	3-year effect (95% CI)	5-year effect (95% CI)
Total household income (%)	+5.0 (2.1, 8.0)	+8.0 (4.2, 11.8)	+10.0 (6.0, 14.0)

Outcome	1-year effect (95% CI)	3-year effect (95% CI)	5-year effect (95% CI)
Non-farm income (%)	+8.2 (3.5, 12.9)	+12.4 (6.8, 18.0)	+15.3 (9.0, 21.6)
Farm income (%)	+1.1 (-1.8, 4.0)	+1.8 (-2.0, 5.6)	+2.0 (-2.5, 6.5)

Source: Authors' calculations based on village-level electrification records from the Township Electrification Program (TEP) and Village Electrification Program (VEP), socio-economic indicators from the National Bureau of Statistics of China, and supplementary administrative data compiled for this study (Xie et al., 2011; Zhang & He, 2013).

The structure of these findings is analytically important. The absence of a statistically significant effect on farm income suggests that electrification was not primarily operating through direct increases in agricultural productivity. Instead, the stronger non-farm effect indicates that electricity expanded opportunities in small-scale enterprise, services, processing, storage, and wage work that depend on a more reliable power supply. In practical terms, electrified households may have been better able to use electric tools, refrigeration, communication devices, and lighting, extending working hours beyond daylight. This interpretation is consistent with the broader literature showing that the developmental returns to electrification often emerge most clearly through livelihood diversification and non-farm income growth rather than through immediate gains in farm production (Khandker et al., 2012; Van de Walle et al., 2017).

The magnitude of the effect is also economically meaningful. A 10.0% increase in total household income after five years, combined with a 15.3% increase in non-farm income, suggests that electrification functioned as more than a welfare subsidy or infrastructure upgrade. Rather, it appears to have expanded the productive capacity of rural households over time. In this sense, the findings strongly support H1 and reinforce the argument that rural solar electrification in China operated as a development intervention with measurable economic returns.

Educational Outcomes

The educational results also support H2. As presented in Table 2, children in electrified villages completed, on average, 0.10 additional years of schooling one year after electrification, 0.32 additional years after three years, and 0.50 additional years after five years. Enrollment rates followed the same direction, increasing by 2.1 percentage points in the first year, 4.5 percentage points after three years, and 6.3 percentage points after five years. Daily study time also rose steadily, from an additional 5.2 minutes per day after one year to 12.5 minutes after three years

and 20.0 minutes after five years. Taken together, these findings indicate that the educational benefits of electrification were not only positive, but also cumulative.

Table 3. Impact on Educational Outcomes (Regression Estimates)

Outcome	1-year effect (95% CI)	3-year effect (95% CI)	5-year effect (95% CI)
Years of schooling (child)	+0.10 (0.02, 0.18)	+0.32 (0.12, 0.52)	+0.50 (0.30, 0.70)
Enrollment rate (percentage points)	+2.1 (0.5, 3.7)	+4.5 (1.8, 7.2)	+6.3 (3.1, 9.5)
Daily study time (minutes)	+5.2 (1.0, 9.4)	+12.5 (6.2, 18.8)	+20.0 (12.5, 27.5)

Source: Authors' calculations based on village electrification records, Ministry of Education administrative data, and supporting household-level information from the China Health and Nutrition Survey (CHNS), matched to treated and comparison villages through the DiD–PSM framework (Zhang & He, 2013; Peng et al., 2022).

These results suggest that electrification improved the conditions under which children studied and remained engaged in formal education. The first-year effects are relatively modest, but the gains become considerably larger after three and five years, which is theoretically plausible. Electricity does not transform educational outcomes overnight; rather, it gradually changes the household learning environment. Better lighting extends study hours after dark, especially in rural communities where children often divide their time between schooling and domestic or agricultural responsibilities. Electrification may also improve school participation indirectly by reducing household constraints and increasing the expected returns to education as local economic opportunities expand.

The consistency across all three indicators years of schooling, enrollment, and study time strengthens the credibility of the education channel. These are not isolated improvements in a single schooling measure, but a broader pattern of improved educational access and engagement. This finding is in line with earlier work showing that electrification can contribute to human capital formation by extending study time and improving the home environment for learning (Khandker et al., 2012; Zhang & He, 2013). Overall, the educational results provide clear support for H2 and indicate that rural solar electrification generated meaningful benefits beyond household income alone.

Health Outcomes

The health results likewise support H3. As shown in Table 3, the incidence of child respiratory illness declined by 0.8 percentage points one year after electrification, 3.2 percentage points after three years, and 5.0 percentage points after five years. Annual health visits per capita also fell modestly, from 0.05 fewer visits in the first year to 0.12 fewer visits after three years and 0.18 fewer visits after five years. At the same time, self-reported health improved steadily, increasing by 0.10 points in year 1, 0.25 points in year 3, and 0.35 points in year 5. Taken together, these indicators point to a coherent improvement in household well-being rather than an isolated change in one narrow health outcome.

Table 4. Impact on Health Outcomes (Regression Estimates)

Outcome	1-year effect (95% CI)	3-year effect (95% CI)	5-year effect (95% CI)
Child respiratory illness incidence (%)	-0.8 (-1.5, -0.1)	-3.2 (-5.0, -1.4)	-5.0 (-7.2, -2.8)
Annual health visits per capita	-0.05 (-0.09, -0.01)	-0.12 (-0.20, -0.04)	-0.18 (-0.28, -0.08)
Self-reported health (scale 1–5)	+0.10 (0.02, 0.18)	+0.25 (0.10, 0.40)	+0.35 (0.15, 0.55)

Source: Authors' calculations based on village electrification records, Ministry of Health administrative indicators, and supplementary health and household welfare information from the China Health and Nutrition Survey (CHNS), combined with the study's matched village panel (Xie et al., 2011; Zhang & He, 2013).

The decline in respiratory illness is particularly important because it aligns with one of the most plausible welfare mechanisms associated with cleaner household energy use. In rural communities that previously relied on kerosene, coal, or other polluting fuels for lighting and basic domestic energy services, electrification may reduce indoor smoke exposure and improve household air quality. The simultaneous increase in self-reported health strengthens this interpretation, suggesting that electrification improved everyday well-being rather than affecting only one clinical indicator. Better lighting may also have supported safer household routines, improved food handling, and a more stable domestic environment overall.

The reduction in annual health visits should, however, be interpreted with some care. On its own, fewer visits could be read in more than one way. In the context of the other indicators reported here, it is more plausibly interpreted as reflecting a lower illness burden and reduced need for treatment rather than declining access to healthcare. Because respiratory illness falls and self-reported health improve at the same time, the overall pattern points to better health

conditions rather than withdrawal from medical services. Even with this caution, the health findings remain substantively important. They suggest that the benefits of electrification extend beyond income generation and schooling to include improvements in daily health conditions and quality of life. In this sense, the evidence supports H3 and reinforces the broader welfare argument advanced in this paper.

Discussions

Taken together, the results provide consistent support for the central claim of this study: rural solar electrification in China generated multidimensional welfare gains that extended beyond the narrow objective of electricity access itself. Across the three hypotheses, the empirical pattern is notably coherent. Income rose, but the gains were concentrated in non-farm activities rather than farm production. Educational outcomes improved across attainment, enrollment, and study time, with effects strengthening over time. Health outcomes also moved in a favorable direction, particularly through lower respiratory illness and better self-reported health. This combination of findings suggests that electrification functioned not merely as a technical infrastructure intervention but as a broader development strategy that affected how rural households worked, studied, and managed daily well-being. China is one of the important Player of BRICS. Through BRICS forum, China is trying to explore new avenues for energy security (Nandy & Islam, 2024).

The temporal pattern is equally important. In all three domains, the estimated effects are larger after three and five years than after one year. This suggests that the benefits of electrification were cumulative rather than instantaneous. Households appear to have needed time to adapt to new energy access, incorporate electricity into productive uses, reorganize study routines, and experience the health gains associated with cleaner and more reliable energy. This dynamic pattern reinforces the argument developed in the introduction and literature review that rural electrification should be evaluated not only in terms of access provision but also in how electricity gradually reshapes socio-economic life in underserved communities.

Overall, the findings position China's rural solar electrification programs as more than an energy policy alone. They show that electrification can contribute simultaneously to livelihood diversification, human capital formation, and better household well-being. In that sense, the results support the paper's broader argument that rural solar electrification should be understood as an integrated development intervention with implications for poverty reduction,

rural revitalization, and sustainable welfare improvement. Energy security is one of the key issue for every country. Over dependency on Middle-east countries for conventional fuel is very uncertain (Nandy, 2020). So, China is emphasizing to produce energy by its own.

Policy Implications

The findings of this study carry important implications for rural energy policy in China and, more broadly, for the design of electrification programs in remote and underserved areas. First, the results suggest that the success of rural electrification should not be evaluated solely in terms of technical indicators such as the number of villages connected, installed capacity, or electrification coverage rates. While these measures remain important, the evidence presented in this study shows that the benefits of electrification extend well beyond physical access to electricity. Rural solar electrification was associated with higher household income, stronger educational outcomes, and improved health conditions, indicating that energy access should be assessed as part of a wider rural development agenda rather than as a narrowly technical infrastructure target.

Second, the income results imply that rural electrification policy is likely to be most effective when it is linked to local economic development strategies, particularly those that support non-farm livelihood diversification. The strongest income gains in this study were found in non-farm income rather than farm income, suggesting that electricity created new opportunities in services, processing, storage, retail, and other small-scale rural enterprises that rely on reliable power. This means that electrification programs should ideally be complemented by policies that expand access to rural credit, local business support, skills training, market linkages, and transport infrastructure. Without such complementary measures, electricity access may improve household welfare, but its productive potential may remain underutilized. In this sense, the policy value of solar electrification lies not only in energy provision itself, but also in its ability to enable a broader transformation of the rural non-farm economy (Khandker et al., 2012; Van de Walle et al., 2017).

Third, the educational and health findings suggest that rural electrification should be integrated more explicitly with social policy objectives. The evidence that electrification improved school participation, years of schooling, and daily study time indicates that energy access can support human capital formation over the longer term. Likewise, the reduction in

child respiratory illness and improvement in self-reported health point to the importance of cleaner household energy environments for rural well-being. These findings imply that electrification programs should be coordinated not only with economic development planning, but also with education and health service delivery. For example, the developmental impact of rural solar programs may be strengthened when village electrification is accompanied by improved school facilities, better digital access, health outreach services, and local investments in clean household energy use. Such an integrated approach would be more consistent with the multidimensional nature of the welfare gains identified in this study.

Finally, the temporal pattern of the results carries a practical policy lesson: the benefits of electrification are cumulative and may take time to materialize. Across income, education, and health, the estimated effects are consistently larger after three and five years than after one year. This suggests that policy evaluation frameworks should avoid judging rural electrification programs too quickly or too narrowly on the basis of immediate post-installation outcomes. In remote rural areas, households need time to adapt to new energy access, invest in productive uses, change domestic routines, and incorporate electricity into educational and health-related practices. As a result, the full developmental value of solar electrification may only become visible over a medium-term horizon. For policymakers, this means that program evaluation should include longitudinal welfare indicators rather than relying exclusively on short-term infrastructure targets.

Broader Development Impact of Rural Solar Electrification

Beyond the immediate policy implications, the findings also speak to the broader developmental significance of rural solar electrification in China. The results suggest that electrification was not merely an energy access intervention, but part of a wider process of rural socio-economic transformation. The combined improvements in household income, educational outcomes, and health indicators indicate that electricity can reshape everyday life in ways that reinforce multiple dimensions of welfare simultaneously. Higher non-farm income can strengthen household resilience and reduce vulnerability to agricultural shocks; improved educational participation can enhance long-term human capital formation; and better health conditions can support productivity, well-being, and the capacity of households to benefit from other development opportunities. These channels are mutually reinforcing, which means that the

developmental value of electrification cannot be understood by examining any one outcome in isolation.

This broader impact is especially relevant in the context of rural China, where electrification has long been tied to state-led efforts to reduce regional inequality, alleviate poverty, and improve living standards in remote communities. In such settings, access to reliable electricity can help narrow the gap between urban and rural areas not only by providing a basic service, but also by enabling the kinds of economic and social improvements that are often concentrated in better-connected regions. The evidence from this study suggests that solar electrification contributed to this equalizing process by improving the welfare conditions of villages that had historically faced infrastructure disadvantages. In that sense, the results align with the wider development rationale behind China's township and village electrification programs, which were designed not only to expand energy access, but also to support more inclusive patterns of rural development (Xie et al., 2011; Zhang & He, 2013).

The findings also contribute to current debates on the role of renewable energy in sustainable development. Rural solar electrification is often discussed in relation to decarbonization, energy transition, and environmental sustainability. Those dimensions are clearly important, but the present results suggest that the value of solar energy in rural settings should also be assessed through its social and developmental consequences. When renewable energy programs improve income opportunities, educational attainment, and health conditions, they do more than reduce carbon dependence; they become instruments of social development and welfare expansion. This point matters because it shifts the policy conversation from a narrow emphasis on clean energy deployment toward a more integrated understanding of how renewable energy can contribute to inclusive development in underserved communities.

At the same time, the findings also imply that electrification alone should not be romanticized as a complete solution to rural poverty or underdevelopment. The positive effects identified in this study are meaningful, but they do not eliminate the need for complementary investments in transport, education quality, healthcare provision, agricultural modernization, and local institutional capacity. Electrification can relax a major infrastructure constraint, but its full benefits depend on whether households and communities are able to convert access into productive and social gains. For this reason, the broader impact of rural solar electrification should be understood as catalytic rather than self-sufficient. It creates enabling conditions for

development, but the depth and sustainability of those gains still depend on the wider policy environment in which electrification takes place.

Taken together, these results position rural solar electrification as a strategically important component of sustainable rural development. In the Chinese case, solar-based electrification appears to have generated benefits that cut across economic, educational, and health dimensions, thereby reinforcing its value not only as an energy intervention but also as a mechanism of rural transformation. More broadly, the findings suggest that renewable electrification programs in remote areas should be viewed as part of a long-term development strategy—one that connects clean energy access with poverty reduction, human capital formation, and improvements in everyday quality of life.

5. CONCLUSION

This study set out to examine the socio-economic implications of rural solar electrification in China by focusing on three interrelated dimensions of household welfare, namely income, education, and health. Rather than approaching electrification merely as a matter of technical access to energy, the analysis treated it as a developmental intervention whose effects may gradually unfold across multiple aspects of rural life. Based on the Difference-in-Differences model combined with Propensity Score Matching, the findings suggest that rural solar electrification generated positive and statistically meaningful welfare effects, although the intensity and channels of impact varied across outcome categories.

The results show, first, that electrification was associated with higher household income, with the most pronounced gains emerging in non-farm income rather than farm income. This pattern indicates that the economic value of electrification in rural areas was linked less to immediate changes in agricultural production and more to the expansion of non-agricultural livelihood opportunities, including small-scale enterprise, rural services, processing activities, and wage employment. Second, electrification was found to improve educational outcomes, as reflected in additional years of schooling, higher school enrollment, and longer study time among children in electrified villages. These findings suggest that electricity improved the domestic conditions under which education takes place, while also strengthening the capacity of rural households to sustain children's participation in schooling over time. Third, the health-related findings point in a similarly positive direction. Lower respiratory illness among children, fewer

annual health visits, and improved self-reported health collectively indicate that electrification contributed not only to energy access, but also to better living conditions and everyday well-being at the household level.

Taken together, these findings suggest that the developmental significance of rural solar electrification lies in its multidimensional effects rather than in electricity provision alone. The contribution of electrification in this study was not confined to lighting homes or extending formal access to power; it also appears to have altered, in gradual but meaningful ways, the economic, educational, and health-related conditions under which rural households reproduce their livelihoods. In this respect, the evidence supports the view that electrification should be understood not simply as infrastructure delivery, but as part of a broader process of rural socio-economic transformation.

An equally important conclusion concerns the timing of these effects. Across the three outcome domains, the estimated impacts tended to become stronger after three and five years than after one year, suggesting that the benefits of electrification were cumulative rather than immediate. This temporal pattern matters because it implies that the value of rural electrification cannot be adequately assessed through short-term access indicators alone. Households require time to adapt to newly available electricity, integrate it into productive and domestic routines, and convert access into more durable welfare gains. The findings therefore reinforce the importance of evaluating electrification not only in terms of infrastructure expansion, but also in terms of the medium- and longer-term social and economic changes that follow from it.

The study also carries a broader policy message. If the benefits of rural solar electrification extend into income diversification, educational participation, and health improvement, then electrification policy should not be designed in isolation from wider rural development objectives. Its developmental returns are likely to be greater when energy access is accompanied by support for rural enterprise, local market participation, educational opportunity, and improvements in household welfare conditions. In that sense, the relevance of solar electrification lies not only in its contribution to renewable energy transition, but also in its capacity to serve as an enabling foundation for more inclusive rural development.

At the same time, the findings should be interpreted with appropriate caution. This study focuses on selected welfare indicators and is therefore unable to capture the full range of long-term social changes associated with electrification. Likewise, although the combined DiD–PSM

framework strengthens the empirical design, the analysis remains constrained by the availability and structure of secondary data, particularly in relation to unobserved local variation across villages and households. Future research could build on these findings by examining regional heterogeneity, differences across household groups, and the specific mechanisms through which electrification shapes non-farm employment, educational attainment, and health-related behavior in rural communities.

Overall, this study concludes that China's rural solar electrification programs produced benefits that extended beyond the narrow provision of energy access. Electrification was associated with higher household income, stronger educational outcomes, and improved health conditions, with these effects becoming more visible over time. In this respect, rural solar electrification should be viewed not merely as an energy intervention, but as part of a wider developmental architecture through which renewable energy can contribute to poverty reduction, human capital formation, and improvements in rural quality of life. For countries seeking to expand renewable energy access in underserved regions, the Chinese experience offers an important lesson: when supported by an enabling socio-economic environment, solar electrification can function not only as a tool of energy transition, but also as an instrument of inclusive and sustainable rural development.

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